NASA'S Microgravity Science Research Program

1995 ANNUAL REPORT

Microgravity offers scientists another tool, albeit a powerful one, to pursue and enhance their mainstream traditional laboratory science endeavors in biotechnology, combustion science, fluid physics, materials science, and low-temperature microgravity physics. In this way, microgravity experiments compliment an investigators conventional ground-based pursuit of increased understanding of a process or phenomena and provides insight and advancement in knowledge which would otherwise be impossible.

EXECUTIVE SUMMARY

The ongoing challenge faced by NASA's Microgravity Science Research Program in Fiscal Year 1995 and every year is to work with the scientific and engineering communities to secure the maximum return from our Nation's investments by: (1) assuring that the best possible science emerges from the science community for microgravity investigations; (2) ensuring the maximum scientific return from each investigation in the most timely and cost-effective manner; and (3) enhancing the distribution of data and applications of results acquired through completed investigations to maximize their benefits. We continued to meet this challenge in Fiscal Year (FY) 1995.

NASA continued to build a solid RESEARCH COMMUNITY of Microgravity Researchers for the coming space station era. During FY 1995, three new NASA Research Announcements (NRAs) were released, and researchers were selected from proposals received in response to an FY 1994 announcement. The principal investigators chosen from these NRAs will form the core of the program at the beginning of the space station era. The number of principal investigators increased almost 20 percent over FY 1994, the number of journal articles increased 41 percent, and the number of technical presentations increased 30 percent. The total number of tasks funded grew from 316 in FY 1994 to 347 in FY 1995. The Space Studies Board of the National Research Council released a report on Microgravity Research Opportunities in the 1990s defining priorities for the microgravity research program in the coming years; this report is a follow-on to the National Research Council's 1992 report entitled Toward a Microgravity Research Strategy.

Continuing strides made in international and INTER-GOVERNMENTAL cooperation. The Space Shuttle made two historic linkups with the Mir space station in June and November of 1995. Data from microgravity equipment placed on Mir are currently being analyzed by NASA microgravity scientists and engineers. Planning for International Space Station facilities continued with respect to the Biotechnology

Facility, the Space Station Furnace Facility, the Fluids and Combustion Facility, and a newly planned Low-Temperature Microgravity Physics Facility. In the microgravity combustion science area, interactions between NASA and the New Energy and Technology Development Organization of Japan were further expanded, with testing by US investigators in the Japanese Microgravity Facility in Hokkaido. Cooperation with the National Institutes of Health (NIH) continued to yield useful results through cooperative use of NASA's bioreactor technology. NASA worked with the National Eye Institute towards the anticipated transfer of NASA technology involving the use of laser light scattering to detect early signs of the onset of cataract formation.

Second United States Microgravity Laboratory (USML-2) and other shuttle missions YIELDED significant results for microgravity experiments. USML-2 yielded a wealth of microgravity data. In the fluid physics area, the Surface Tension Convection Experiment again provided researchers with the perfect opportunity to examine flows caused by surface tension differences. Experiments on silicone drops with entrapped air bubbles, conducted in the Drop Physics Module, confirmed the expectation that a bubble would move to the center of an oscillating drop in a low-gravity environment due to fluid motion. In the materials science area, USML-2 provided the conditions for growing the thinnest and smoothest mercury cadmium telluride film ever grown. USML-2 was also the first mission to have the Microgravity Acceleration Work Station on board, helping scientists to guide the shuttle crew in making small orientation changes to improve crystal growth conditions. In the biotechnology area, over 1,500 protein samples were flown on USML-2, far surpassing accomplishments on any previous shuttle mission. USML-2 Glovebox experiments also yielded important results in the areas of fuel droplet combustion, thermocapillary flows, equilibrium liquid-vapor interfaces, protein crystal growth, zeolite crystal growth, colloidal disorder-order transitions, and particle dispersion. The February 1995 STS-63 and March 1995 STS-67 Shuttle missions also provided excellent protein crystals. The Solid Surface Combustion Experiment successfully completed its multi-mission protocol on the STS-63 mission with burning of polymethylmethacrylate samples in a highly oxygenated atmosphere. In addition, two Microgravity Smoldering Combustion tests were conducted on the September, 1995 STS-69 Shuttle mission.

Microgravity research program expands Education and Outreach activities. In FY 1995, approximately 3,000 sites requested materials and information regarding "Putting the Tgee!' in Microgravity" national television broadcast. This program was developed by NASA's Education Division as one of four programs in its "Explorations in Science, Mathematics & Technology" series for pre-college audiences. The live broadcast involved interactive communication via telephone and NASA Spacelink, an electronic database of space-related information, and several NASA scientists and educators at three uplink sites. Microgravity News, which provides quarterly updates on NASA's Microgravity Science Research Program, has been reaching increasing numbers of people in the past year. The December 1995 mailing list included almost 2500 subscribers, up from 934 in January 1995. The Microgravity Science Research Program World Wide Web Home Page has been updated to provide a seamless connection to NASA's "Microgravity Science Information System." The hyperlink includes access to a Catalog of Flight Hardware, Alternate Carriers for Experiments, Space Station Flight Hardware, Spacelab Hardware, and the International Standard Payload Rack Vibration Analysis.

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1: INTRODUCTION

This report describes key elements of the NASA Microgravity Science Research Program as conducted by the Microgravity Science and Applications Division within NASA's Office of Life and Microgravity Sciences and Applications during FY 1995. Summarized are the program's goals, the approach taken to achieve those goals, and the resources that were available. A RsnapshotS of the Program's status at the end of FY 1995 and a review of highlights and progress in the ground and flight-based research during the year are provided. Also described are major space missions that flew during FY 1995, plans for utilization of the research potential of the Russian Mir Station and the International Space Station, the Advanced Technology Development Program, and various educational/outreach activities. This NASA funded program supports investigators from university, industry, and government research communities needing a space environment to study phenomena affected directly or indirectly by gravity.

The Microgravity Science Research Program is a natural extension of traditional Earth-based laboratory science, in which experiments performed benefit from the stable, long-duration microgravity environment available in orbiting spacecraft. The microgravity environment affords substantially reduced buoyancy forces, hydrostatic pressures, and sedimentation rates, allowing gravity-related phenomena and phenomena masked by gravity on Earth to be isolated and controlled, and permitting measurements to be made with an accuracy that cannot be obtained on Earth.

The Microgravity Science Research Program conducts a program of basic and applied research in five areas:

1. **Biotechnology**, focusing on macromolecular crystal growth as well as cellular response to low stress environments
2. **Combustion Science**, focusing on processes of ignition, propagation and extinction during combustion of gaseous, liquid, and solid fuels and on combustion synthesis in a low-gravity environment
3. **Fluid Physics**, including aspects of fluid dynamics and transport phenomena affected by the presence of gravity
4. **Materials Science**, including electronic and photonic materials, glasses and ceramics, polymers, and metals and alloys
5. **Low-Temperature Microgravity Physics**, including the study of critical phenomena, low temperature, atomic, and gravitational physics, and other areas of fundamental physics where significant advantages exist for studies in a low gravity environment.

Experiments in these areas are typically directed at providing a better understanding of gravity-dependent physical phenomena and exploration of phenomena made obscure by the effects of gravity. Scientific results are used to challenge or validate contemporary scientific theories, to identify and describe new experimental techniques that are unique to the low-gravity environment, and to engender the development of new theories explaining unexpected results. These results and the improved understanding accompanying them can lead to improvements in combustion efficiency and fire safety, to reduction of combustion-generated pollutants, to new technologies in industries as varied as medicine, chemical processing, and materials processing, to development or improvement of pharmaceuticals, and to expansion of fundamental knowledge in a broad range of science disciplines that will become the foundation for science and technology discoveries in the future.

A complementary document to this annual report is the "Microgravity Science and Applications Program Tasks and Bibliography for FY 1995," NASA Technical Memorandum 4735, March 1996. Detailed information on the research tasks funded by the microgravity program during FY 1995 are listed in that report, which serves as an excellent reference for supplementary information to this annual report. Also of interest is the RNASA Microgravity Science and Applications Program Strategic PlanS issued in June of 1993, a guide for development and implementation of the Microgravity Science Research Program plans and activities to the year 2000. Another complementary document is NASA's Microgravity Technology Report, first published in December 1995, summarizing advanced technology development and technology transfer activities through FY 1994. A second edition covering FY 1995 activities will be published in early summer, 1996.

Table 1.1 summarizes information from the program task book which may be of particular interest to the reader. Data for FY 1992, FY 1993, and FY 1994 are shown for comparison with FY 1995 information.

Table 1.1 FY 1992 through 1995 Research Task Summary: Overview Information and Statistics

	FY 1992	FY 1993	FY 1994	FY 1995
Total Number of Principal Investigators	144	196	243	2
Total Number of Co-Investigators	*	268	252	2
Total Number of Research Tasks	144	243	315	3
Total Number of Bibliographic Listings	559	767	944	1,2
• Proceeding Papers	69	110	145	1
• Journal Articles	302	446	371	5
• NASA Technical Briefs	6	6	13	
• Science/Technical Presentations	178	201	391	5
• Books/Chapters	4	5	24	
Total Number of Patents Applied for or Awarded	7	7	4	
Number of Graduate Students Funded	242	329	434	5
Number of Graduate Degrees Based on MSAD-funded Research	61	61	125	1
Number of States With Funded Research (including District of Columbia)	32	32	36	

FY Microgravity Science & Applications Budget (in millions)	120.8	179.3	188.0	16

* Information not collected.

Microgravity Science & Applications Research Tasks and Types Responsibilities by Center

Center, Types of Research	Ground				Flight				Advanced Technology Development				Center	
(by Fiscal Year)	'92	'93	'94	'95	'92	'93	'94	'95	'92	'93	'94	'95	'92	'93
Jet Propulsion Laboratory	13	29	29	28	4	7	7	5	2	3	3	3	19	39
Johnson Space Center	2	11	10	34	1	1	0	1	0	0	0	0	3	12
Langley Research Center	4	5	3	3	1	2	2	2	1	1	0	0	6	8
Lewis Research Center	45	87	130	125	19	29	35	32	5	5	5	6	69	121
Marshall Space Flight Center	19	36	62	76	18	25	25	25	2	2	4	6	39	63
Goddard Space Flight Center	0	0	0	0	0	0	0	0	0	0	1	1	0	0
NASA Headquarters	8	0	0	0	0	0	0	0	0	0	0	0	8	0
Research Task Totals	**91**	**168**	**233**	**266**	**43**	**64**	**69**	**65**	**10**	**11**	**13**	**16**	**144**	**243**

2: PROGRAM GOALS FOR FY 1995

The NASA Microgravity Science Research Program during FY 1995 was evolved and implemented using a plan that integrated science, applications, technology development, and technology transfer objectives. Microgravity research forms a key component of NASA's Human Exploration and Development of Space strategic enterprise. The Program's mission during this period was:

To use the microgravity environment of space as a tool to advance knowledge; to use space as a laboratory to explore the nature of physical phenomena, contributing to progress in science and technology on Earth; and to study the role of gravity in *technological processes, building a scientific foundation for understanding the consequences of gravitational environments beyond Earth's boundaries.*

The Microgravity Science Research Program goals for FY 1995 were to:

Goal 1: Further advance a research program focused in the areas of biotechnology, combustion science, fluid physics, materials science, and selected investigations in low temperature microgravity physics.

Goal 2: Foster an interdisciplinary community to promote synergism in carrying out the research program.

Goal 3: Enable research through the development of an appropriate infrastructure of ground-based facilities, diagnostic capabilities, and flight facilities/opportunities to meet science requirements.

Goal 4: Promote the exchange of scientific knowledge and technological advances among academic, governmental and industrial communities and disseminate results to public and educational institutions.

Goal 5: Increase United States research opportunities in space through international cooperative efforts.

3: PROGRAM APPROACH FOR FY 1995

Program Overview

The Microgravity Science Research Program conducts space research using an established process to select scientific investigations via periodic release of NASA Research Announcements with external peer review of proposals received in response to these announcements. FY 1995 was a record year for NASA Research Announcements in the area of Microgravity Science with the release of three announcements in the areas of Microgravity Combustion Science, Microgravity Fluid Physics/Microgravity Low-Temperature Physics, and Microgravity Materials Science. Selections for the Biotechnology NASA Research Announcement (released in FY 1994) were also made in FY 1995. All new investigations are selected by the external peer review process for either ground-based studies or flight definition studies. In the latter case, there is an initial ground-based definition phase to establish the concept, verify the need for flight experiments, and define the scope of these experiments; further peer review is then utilized to determine which of the flight definition experiments will actually be approved for progress to use of space facilities. With this overall approach, research within the microgravity program extends from analytical studies and relatively low-resource ground-based experimental studies to substantial space-flight experiments.

The Microgravity Science Research Program supports a relatively large number of analytical studies and experimental studies utilizing ground-based facilities, development of high-quality flight investigations, and further development of ground-based facilities and advanced diagnostics for both ground-based and flight experiments. In the ground-based facilities, low-gravity test environments of varying duration are available; up to five seconds of high-quality microgravity time in drop tubes/towers, 20 seconds of considerably lower quality microgravity time in aircraft, and up to 12 minutes of high-quality microgravity time in suborbital rockets. To support the space-based investigations, the flight program selects the most cost-effective option from a broad range of hardware and carrier resources.

To ensure the best use of resources and scientific talent to achieve program goals, the Microgravity Science Research Program observes the following decision rules to guide the process:

- Maintain and, when successive peer-evaluation warrants, complete the ongoing program.
- Identify and nurture emerging experimental concepts and areas of investigation with high scientific potential.
- Identify and sustain a broad capability for experimentation in space, utilizing all available carriers.
- Identify and pursue initiatives to support effective changes and growth within the Microgravity Science Research Program.

These decision rules are discussed in more detail in the NASA Microgravity Science and Applications Program Strategic Plan published in 1993.

National Institutes of Health Cooperation

The FY 1994 and FY 1995 NASA Appropriations included augmentations totaling $20 million for collaborative NASA-NIH Biotechnology programs. In using these funds, the NASA areas of emphasis are:

- Establishment of joint NASA-NIH centers that will accelerate the transfer of NASA technology and allow its application to biomedical research;
- Development of advanced tissue culturing technology and application of this breakthrough technology to biomedical research and developmental biology;
- Development of advanced protein crystallization technologies to advance structural biology and drug design to fight a number of diseases, and;
- Development of technology for the early detection of cataracts.

The NASA-NIH collaboration offers an opportunity to address the technical challenges of three-dimensional tissue growth, crystallization of high quality protein crystals, and the early detection of cataracts by supporting multi-disciplinary research teams. These research teams allow the best American scientists and bioengineers to address these complex problems and accelerate development of the technologies. For acceleration of the pace of technology transfer in the biotechnology areas begun under the NASA-NIH inter-agency agreement, two multidisciplinary research centers are currently supported: Massachusetts Institute of Technology in Cambridge and the Wistar Institute in Philadelphia. Through NASA-NIH cooperation, NASA has funded approximately 28 research proposals and has also supported NIH-approved researchers to test tissue samples in NASA bioreactors at NASA's Johnson Space Center. This has proven to be a very important undertaking in getting researchers to test NASA technology and in gaining acceptance in the larger biomedical community.

A cooperative effort was initiated with the National Institute of Child Health and Human Development in the fall of 1994 to transfer NASA's bioreactor technology so that it can be used in the area of AIDS research, with researchers using cultures of human tonsil, lung, adenoid, and lymph node to assess infectivity of HIV virus on the tissues.

The microgravity research program is currently working with the NIH National Eye Institute to transfer NASA technology involving the use of laser light scattering to detect early signs of the onset of cataract formation. Work at NASA's Lewis Research Center demonstrated that this technology could be used to measure the size distribution of a protein in the eye that is related to the early development stages of cataracts; discussions with managers from the NIH National Eye Institute led to the decision to proceed with development of a prototype diagnostic tool. Subsequent to successful demonstration, the National Eye Institute is interested in obtaining the technology for use in a large scale clinical trial. The Microgravity program is also collaborating with researchers at the National Eye Institute using protein crystal growth technology to determine structures of important proteins related to the signal pathway for sight through a joint program between NASA, NIH, and Eli Lilly and Company.

The Microgravity program also has collaborative work with the National Institute of Allergies and Infectious Diseases, National Cancer Institute, and the National Institute of Diabetes and Digestive and Kidney Diseases. NASA is working with NIH to establish an additional NASA bioreactor facility in the laboratory at the National Cancer Institute.

International Cooperation

Russian Mir Space Station

FY 1995 was one of NASA's biggest years ever for international activities, with the Microgravity program playing a large role in making this possible. The Shuttle and Mir Space Station made a historic linkup in June, 1995. Under an exciting cooperative agreement with Russia, the Space Shuttle could make up to 10 dockings to the Mir Station. During FY 1995, Microgravity Science Research Program researchers began to receive Space Acceleration Measurement System data from the Mir. These instruments have flown 10 times aboard the Space Shuttle to characterize the on-orbit acceleration environment, but 1995 was the first time an instrument has flown aboard Mir (in response to the National Research Council recommendation in 1992 to measure acceleration on all spacecraft utilized in the Microgravity research program). These acceleration data will help investigators plan experiments for future flights aboard Mir, allowing scientists and hardware developers to provide appropriate isolation for their experiments and assure the best possible science in the Mir environment.

The NASA/Mir program allows NASA to practice techniques that are key to the success of space station research. NASA will use some of its allocated resources on Mir to maintain several biotechnology facilities. New technology for protein crystal growth and bioreactors for cell tissue growth will be tested, with the samples being exchanged with every shuttle flight to Mir. Microgravity researchers also hope to gain added data by placing a Glovebox onboard Mir for materials, combustion, and fluids experiments. In addition, the Canadian Microgravity Isolation Mount will be installed on Mir to permit the conducting of several small scientific and technological experiments using this hardware which provides a platform that is isolated from the vibration environment of Mir and can also be used to produce specific accelerations for study of controlled acceleration effects. As with the biotechnology hardware and Glovebox, the isolation mount hardware will remain onboard Mir for the duration of the NASA-Mir program, with NASA rotating experiments in and out while perfecting the new techniques necessary for the successful use of the Space Station.

International Space Station

FY 1995 also witnessed tremendous strides in the development of facilities for the International Space Station. An international conference, where agencies disclosed their plans for station furnaces and looked for elements that overlapped, was hosted by the European Space Agency in the Netherlands in June 1994. In March 1995, the international partners met again in Huntsville, Alabama, to discuss potential furnace facilities. Since NASA desired a crystal growth facility on the station earlier than the European Space Agency's (ESA) schedule would allow, NASA proposed providing a modified version of our Crystal Growth Furnace as part of the early station program. The European Space Agency could then continue development of its more sophisticated crystallization furnace, with the two agencies exploring a utilization exchange; this exchange could save the United States the time and expense of developing second-generation hardware and allow NASA to turn its energies elsewhere. Since the French Space Agency built MEPHISTO, a solidification furnace that flew on the United States Microgravity Payload missions in 1992 and 1994, France has significant expertise to offer in building the solidification furnace.

Similar efforts are under way for collaboration on the development of hardware for the Fluids and Combustion, and Low-Temperature Microgravity Physics facilities. On April 10-11, 1995, the space station partners convened in Cleveland, Ohio, for an International Workshop on Fluids and Combustion Hardware for the International Space Station. Each partner gave a presentation on their plans with a chart highlighting possible areas for collaboration being compiled in real-time. Most of the possibilities for combining development plans related to the area of fluid physics.

Another step forward in the Space Station partnership occurred in May 1995 in Berlin. Most of the International Space Station partners--ESA and the space agencies of Canada, France, Germany, Japan, and the United States-- agreed to form an International Strategic Planning Group for Microgravity Science and Applications Research. The Russian Space Agency was unable to attend, but an invitation to join the Strategic Planning Group has been extended formally. The purpose of the group is to review on a biennial basis each country's plans for microgravity investigations and to develop an international program. In the process of putting together this overview, the partners should be able to identify areas of unnecessary duplication and potential collaboration for both hardware development and scientific studies.

Advisory Groups

The Microgravity Science Research Program collaborated with and received valuable guidance from several advisory and review groups during FY 1995. Program content, plans, and priorities were reviewed periodically by the Microgravity Science and Applications Advisory Subcommittee, consisting of the chairs of the microgravity Discipline Working Groups, principal investigators, and representatives from industry and academia. The Space Station Utilization Advisory Subcommittee, which includes technology and commercial representatives, continually reviews the program with regard to Space Station utilization. Both are subcommittees of the Life and Microgravity Sciences and Applications Advisory Committee (LMSAAC), a committee of the NASA Advisory Council.

The science Discipline Working Groups for biotechnology, combustion science, fluids physics, and materials science continued the process of recommending discipline refinements and science priorities in FY 1995. The Discipline Working Groups are responsible for maintaining an overview of the efforts in the discipline areas, and for providing an annual program assessment. They are charged with identifying the most promising areas for investigation and most advantageous approaches for experimentation. A low-temperature science steering committee provided external advice related to the emerging microgravity low-temperature physics research field.

The Committee on Microgravity Research (CMGR), a standing committee of the National Research Council's Space Studies Board, released its report Microgravity Research Opportunities for the 1990s, which outlines priorities and recommendations for microgravity science research to the year 2000. The report emphasized that the overarching goal of the microgravity research program should be to advance science and technology in each of its component disciplines, and it identified the following committee findings:

1. *Science can be advanced by the study of certain mechanisms that are masked or dominated by gravitational effects at Earth gravity conditions;*
2. *There is a scientific need to understand better the role of gravity in many physical, chemical, and biological systems;*

3. *A significant portion of microgravity research programs should be driven by the technological needs of the overall space program;*
4. *Microgravity research primarily involves laboratory science with controlled, model experiments that inherently require attention and intervention by the experimenter;*
5. *The potential for manufacturing in space in order to return economically competitive products to Earth is very small, although research on materials processing in microgravity could be important for ground-based materials science and materials processing technology;*
6. *Fluid mechanics and transport phenomena represent both a distinct discipline and a scientific theme that impact nearly all microgravity research experiments; and*
7. *The ground-based research program is critically important for the preparation and definition of the flight program.*

This committee also found that an extended-duration platform in space would help meet critical needs of many microgravity research investigations (i.e. the length of time required for experimentation, the need for wide parametric ranges, and the need to demonstrate the reproducibility of results). Although, in preparing the report, the committee assumed that a space station would be available within a decade, the report clearly states that the recommendations have value and should be implemented even if the microgravity research program must continue with only current facilities.

4: MICROGRAVITY RESEARCH CONDUCTED IN FY 1995

In FY 1995, NASA funded a robust microgravity research program in a variety of microgravity-related disciplines (biotechnology, combustion science, fluid physics, materials science, and low-temperature microgravity physics). Experiments promoted deeper understanding of phenomena within scientific disciplines, and often yielded interdisciplinary benefits. Investigations sponsored as part of the microgravity science program shared one characteristic; they required reduced or near-zero gravity conditions in order to achieve their objectives.

The overall Microgravity Research Program is conducted through integrated ground-based and flight programs. In addition to providing meaningful microgravity results as RstandaloneS programs, the ground-based research program also is used in development of concepts leading to flight experiments, to determine limitations of various terrestrial processing techniques, and to provide analysis and modeling support to the flight program. A successful ground-based research program generally represents a necessary first step toward flight experimentation.

Highlights from the five microgravity disciplines for FY 1995 are presented below.

BIOTECHNOLOGY

Overview

Biotechnology is broadly defined as any technology concerned with research on, manipulation of, and manufacture of biological molecules, tissues, and living organisms to produce or obtain products or perform functions. NASA's microgravity biotechnology program is active in two major areas: protein crystal growth and mammalian cell tissue culture. In the former area, researchers seek to grow protein crystals suitable for structural analysis by X-ray diffraction and to understand how these crystals form. In the second area, investigators study evaluate the benefit of low gravity for growing cells and tissues. NASA's Marshall Space Flight Center in Huntsville, Alabama, is the Microgravity Center of Excellence for Biotechnology, and provides direct support for research in protein crystal growth with NASA's Johnson Space Center in Houston, Texas, providing support for research in cell tissue culturing. NASA is also moving ahead with cooperative activities with NIH described in Section 3 of this report.

Forty-seven researchers were selected in FY 1995 to receive grants under the 1994 Biotechnology NASA Research Announcement. These awards total over $38 million over a four-year period. Funding includes financial support for research centers at the Massachusetts Institute of Technology (Cambridge, MA) and the Wistar Institute (Philadelphia, PA). A cooperative program between NASA and NIH has also been established for support of research utilizing bioreactor technology at NIH's Institute for Child Health and Human Development in Bethesda, MD.

In the area of Protein Crystal Growth, academic, industrial, and Federal Government researchers, armed with advanced biotechnology techniques and detailed data on the structure of key proteins, are creating a new generation of drugs. Researchers use data on the structure of proteins to design drugs at the molecular level that will interact with specific proteins and treat specific diseases. This approach promises to produce superior drugs for a wide range of conditions, replacing the trial and error approach to drug development that has been the rule for centuries. Schering Plough (New Jersey), Eli Lilly (New Jersey), Upjohn (Michigan), Bristol-Myers Squibb (New Jersey), Smith Kline Beecham (Pennsylvania), BioCryst (Alabama), DuPont Merck (Delaware), Eastman Kodak (New York), and Vertex (Massachusetts) are working with NASA's Center for Macromolecular Crystallography to produce high quality protein crystals for new drug development. Researchers have already used Space Shuttle missions to produce superior protein crystals for research on clinical conditions including cancer, diabetes, emphysema, and immune system disorders. Additionally, in collaboration with Eli Lilly and Co., The Hauptman Institute of Buffalo (New York) is using data derived from space experiments on human insulin to design a drug that will bind insulin, thereby improving the treatment of diabetic patients. NASA is also supporting space research on an enzyme that HIV (the virus that causes AIDS) needs to reproduce; this research is directed at better defining the enzyme's structure so that effective inhibiting pharmaceuticals can be developed. Finally, researchers working with NASA's Marshall Space Flight Center are using microgravity to study events that define the initial nucleation of the protein crystal as well as the solution environment of the subsequent crystal growth. Specific examples of activities in the Protein Crystal Growth area are:

- Dr. Mark Wardell of Cambridge University's Department of Hematology grew crystals of human antithrombin III of greatly improved quality, permitting completion of the atomic model for this enzyme.
- Dr. Chong-Whan Chang of DuPont Merck successfully grew improved quality crystals of HIV protease complexes with an inhibitor; crystallographic refinement of the atomic model is in progress.
- Dr. Jean-Pierre Wery and Mr. David Clausen of Eli Lilly and Company grew crystals of Raf Kinase (of great interest in cell and cancer research) which were at least an order of magnitude larger than any previously obtained.
- Dr. B. C. Wang and Dr. John Rose grew improved crystals of Neurophysin/vasopressin complex, important to understanding cardiovascular regulatory processes. In addition, these investigators grew crystals of augmented of Liver Regeneration Protein, a new liver growth factor which promotes liver regeneration following damage or injury, of greatly improved internal order.
- Dr. Jean-Paul Declercq, University of the University of Louvain (Belgium), grew crystals of two proteins, 1-alanine dehydrogenase and lambda phase lysozyme, of improved crystal habit and much larger than any previously obtained.

Growing tissue samples PP tissue culturing -- is one of the fundamental goals of biomedical research; laboratory containers called bioreactors are used to grow, or Rculture,S samples of body tissues. Of major importance, scientists could use cancer tumors and other tissues that are successfully grown outside the body to test and study treatments, like chemotherapy, without risking harm to patients. Tissues from bioreactors will also offer important medical insights into how tissues grow and develop in the body. Highlights of recent research in this area include the following examples:

- Dr. Jeanne Becker, University of South Florida, has applied NASA technology to create a breakthrough in culturing high quality ovarian cancer tumors for cancer research.
- Dr. Lisa Freed, Massachusetts Institute of Technology, is using a NASA bioreactor to grow cartilage cells on biodegradable scaffolds, demonstrating the potential for use of Space Station to produce models and transplantable cartilage tissues that could revolutionize treatment for joint diseases and injuries.

Meetings, Awards, Publications

NASA held an Investigators Working Group Meeting in Houston, Texas, from March 3-4, 1995. Forty researchers attended this meeting and discussed recent advances in three-dimensional tissue culturing using the NASA bioreactor.

The NASA Protein Crystal Conference was held in Panama City, FL from April 22-25, 1995. This meeting addressed fundamental questions in protein crystallization for both flight- and ground-based experiments. There were approximately 20 presentations from NASA and international investigators.

NASA investigators participated in the Society for InVitro Biology Conference in Denver, Colorado, in June 1995. A session of the conference was devoted to the results from tissue culturing research using the NASA bioreactor.

Dr. Alex McPherson, University of California at Riverside, published a paper on the results from the Second International Microgravity Laboratory mission. This paper showed that the results from this mission were consistent with the results from the First Second International Microgravity Laboratory mission and showed dramatic alterations in crystal morphologies, remarkable increases in crystal sizes, and unequivocal improvements in the quality and resolutions of the diffraction patterns for some types of protein crystals. These results are believed to be caused by the microgravity environment of space.

NASA Principal Investigator Dr. Larry DeLucas, University of Alabama at Huntsville, received the 1995 Space Processing Award at the American Institute of Aeronautics and Astronautics meeting held in Reno, Nevada. Dr. DeLucas was nominated by the Space Processing Committee which is comprised of microgravity scientists.

Flight Experiments

The March 1995 STS-67 Shuttle mission marked the second flight of the Protein Crystal Growth Apparatus for Microgravity; crystals were grown by the vapor diffusion/equilibration method with a total of 378 individual experiments housed in a single middeck locker. Numerous diffraction-size crystals were grown on this mission, with 7 out of 8 proteins flown producing useful samples.

During the July 1995 STS-70 mission, a colon carcinoma cell culture in the bioreactor appeared to yield substantially larger tissue assemblies than either of the two ground control unit tests conducted simultaneously at NASA's Kennedy Space Center.

The Second United States Microgravity Laboratory (USML-2), launched on October 25, 1995, included several biotechnology experiments. First, Dr. Dan Carter of NASA's Marshall Space Flight Center flew a record 1005 protein samples in protein crystal growth hardware especially designed to increase the number of protein samples that can fly in the middeck. A total of 11 co-Investigators representing government, industry, and academic laboratories participated in the flight experiment, with 18 different proteins being analyzed. The Second United States Microgravity Laboratory was the third flight of the protein crystal growth apparatus and brought the number of protein crystal growth experiments flown in this hardware close to 1800 for calendar year 1995.

Dr. Carter also tested a new unit referred to as the Diffusion-Controlled Crystallization Apparatus for Microgravity, with 81 sample cells located in the Spacelab module; this equipment demonstrated the hardware's performance capabilities for upcoming Space

Station experiments. In addition, Dr. Alex McPherson, University of California at Riverside, used 12 of the 98 sample chambers in the European Space Agency's Advanced Protein Crystallization Facility in a continuation of cooperative research with the European Space Agency started on the International Microgravity Laboratory missions. Dr. McPherson also demonstrated a new hardware concept by the use of four hand-held test cells.

The FY 1995 ground and flight tasks for biotechnology are listed in Table 4.1.

Table 4.1 Biotechnology Tasks funded by MSAD in FY 1995

Flight Experiments

Protein Crystal Growth Vapor-Diffusion Flight Hardware and Facility			
Dr. Daniel C. Carter	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL
Protein Crystal Growth in Microgravity			
Dr. Lawrence J. DeLucas	University of Alabama, Birmingham	Birmingham	AL
Electrophoretic Separation of Cells and Particles from Rat Pituitary			
Dr. Wesley C. Hymer	Pennsylvania State University	University Park	PA
Growth, Metabolism, and Differentiation of MIP-101 Carcinoma Cells			
Dr. J. M. Jessup	Harvard Medical School	Boston	MA
Membrane Transport Phenomena			
Mr. Larry Mason	Lockheed Martin	Denver	CO
An Observable Protein Crystal Growth Flight Apparatus			
Dr. Alexander McPherson, Jr.	University of California, Riverside	Riverside	CA
Enhanced Dewar Program			
Dr. Alexander McPherson, Jr.	University of California, Riverside	Riverside	CA
Electrophoresis Technology			

Dr. Robert S. Snyder	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Investigation of Protein Crystal Growth Mechanisms in Microgravity

Dr. Keith B. Ward	Office of Naval Research	Washington	DC

Ground Experiments

The Use of Bioactive Glass Particles as Microcarriers in Microgravity Environment

Prof. Portonovo S. Ayyaswamy	University of Pennsylvania	Philadelphia	PA

Evaluation of Ovarian Tumor Cell Growth and Gene Expression

Jeanne L. Becker, Ph.D.	University of South Florida	Tampa	FL

Expansion and Differentiation of Cells in Three Dimensional Matrices Mimicking Physiological Environments

Prof. Rajendra S. Bhatnagar	University of California, San Francisco	San Francisco	CA

Quantitative, Statistical Methods for Pre-Flight Optimization, and Post-Flight Evaluation of Macromolecular Crystal Growth

Prof. Charles W. Carter	University of North Carolina, Chapel Hill	Chapel Hill	NC

Crystallographic Studies of Proteins Part II

Dr. Daniel C. Carter	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Microgravity Simulated Prostate Cell Culture

Prof. Leland W. Chung	University of Virginia	Charlottesville	VA

Noninvasive Near-Infrared Sensor for Continual Cell Glucose Measurement

Dr. Gerard L. Cote	Texas A&M University	College Station	TX

A Comprehensive Investigation of Macromolecular Transport During Protein Crystallization

Dr. Lawrence J. DeLucas	University of Alabama, Birmingham	Birmingham	AL

Development of Robotic Techniques for Microgravity Protein Crystal Growth

Dr. Lawrence J. DeLucas	University of Alabama, Birmingham	Birmingham	AL

Macromolecular Crystallization: Physical Principles, Passive Devices, and Optimal Protocols

Dr. George T. DeTitta	Hauptman-Woodward Medical Research Institute	Buffalo	NY

The Effect of Microgravity on the Human Skin Equivalent

Dr. S. D. Dimitrijevich	Univ. of N. Texas Health Science Ctr, Fort Worth	Fort Worth	TX

Use of Microgravity-Based Bioreactors to Study Intercellular Communication in Airway Cells

Dr. Ellen R. Dirksen	University of California, Los Angeles	Los Angeles	CA

Microgravity Thresholds for Anti-Cancer Drug Production on Conifer Cells

Dr. Don J. Durzan	University of California, Davis	Davis	CA

Laser Scattering Tomography for the Study of Defects in Protein Crystals

Prof. Robert S. Feigelson	Stanford University	Stanford	CA

Role of Fluid Shear on 3-D Bone Tissue Culture

Prof. John A. Frangos	University of California, San Diego	La Jolla	CA

Microgravity Studies of Cell-Polymer Cartilage Implants

Lisa E. Freed, M.D., Ph.D.	Massachusetts Institute of Technology (MIT)	Cambridge	MA

Microgravity Tissue Engineering

Lisa E. Freed, M.D., Ph.D.	Massachusetts Institute of Technology (MIT)	Cambridge	MA

Protein and DNA Crystal Lattice Engineering

Dr. D. T. Gallagher	Center for Advanced Research in Biotechnology (CARB)	Rockville	MD

Microgravity-Based Three-Dimensional Transgenic Cell Models

Dr. Steve R. Gonda	NASA Johnson Space Center (JSC)	Houston	TX

Lymphocyte Invasion Into Tumor Models Emulated Under Microgravity Conditions In Vitro

Thomas J. Goodwin, M.S.	NASA Johnson Space Center (JSC)	Houston	TX

Differentiation of Cultured Normal Human Renal Epithelial Cells in Microgravity

Dr. Timothy G. Hammond	Tulane University	New Orleans	LA

Excitable Cells and Growth Factors under Microgravity Conditions

Dr. Charles R. Hartzell	Alfred I. duPont Institute	Wilmington	DE

Determining the Conditions Necessary for the Development of Functional Replacement Cartilage Using a Microgravity Reactor

Prof. Carole A. Heath	Iowa State University	Ames	IA

The Effects of Microgravity on Viral Replication

John H. Hughes, Ph.D.	Ohio State University	Columbus	OH

Sensitized Lymphocytes for Tumor Therapy Grown in Microgravity

Dr. Marylou Ingram	Huntington Medical Research Institutes	Pasadena	CA

Three-Dimensional Tissue Interactions in Colorectal Cancer Metastasis

Dr. J. M. Jessup	New England Deaconess Hospital	Boston	MA

Fibril Formation by Alzheimer's Disease Amyloid in Microgravity

Prof. Daniel A. Kirschner	University of Massachusetts	Lowell	MA

Applications of Atomic Force Microscopy to Investigate Mechanisms of Protein Crystal Growth

Dr. John H. Konnert	Naval Research Laboratory	Washington	DC

Regulation of Skeletal Muscle Development and Differentiation In Vitro by Mechanical and Chemical Factors

Dr. William E. Kraus	Duke University Medical Center	Durham	NC

Neuro-endocrine Organoid Assembly in Vitro

Dr. Peter I. Lelkes	University of Wisconsin, Milwaukee	Milwaukee	WI

Formation of Ordered Arrays of Proteins at Surfaces

Prof. Abraham M. Lenhoff	University of Delaware	Newark	DE

Multidisciplinary Studies of Cells, Tissues, and Mammalian Development in Simulated Microgravity

Dr. Elliot M. Levine	The Wistar Institute	Philadelphia	PA

Analysis of Electrophoretic Transport of Macromolecules using Pulsed Field Gradient NMR

Dr. Bruce R. Locke	Florida State University	Tallahassee	FL

Ground-Based Program for the Physical Analysis of Macromolecular Crystal Growth

Prof. Alexander J. Malkin	University of California, Riverside	Riverside	CA

Thyroid Follicle Formation in Microgravity: Three-Dimensional Organoid Construction in a Low-Shear Environment

Andreas Martin, M.D.	Mount Sinai School of Medicine	New York	NY

Biological Particle Separation in Low Gravity

Dr. D. J. Morri	Purdue University	West Lafayette	IN

Continuous, Noninvasive Monitoring of Rotating Wall Vessels and Application to the Study of Prostate Cancer

Prof. David W. Murhammer	University of Iowa	Iowa City	IA

Crystallization Studies in Microgravity of an Integral Membrane Protein: The Photosynthetic Reaction Center

Dr. James R. Norris	Argonne National Laboratory	Argonne	IL

Insect-Cell Cultivation in Simulated Microgravity

Prof. Kim O'Connor	Tulane University	New Orleans	LA

Insect-Cell Cultivation in the NASA High Aspect Rotating-Wall Vessel

Prof. Kim O'Connor	Tulane University	New Orleans	LA

Use of Rotating Wall Vessel (RWV) to Facilitate Culture of Norwalk Virus

Dr. Paul E. Oefinger	University of Texas Medical School at Houston	Houston	TX

Shear Sensitivities of Human Bone Marrow Cultures

Dr. Bernhard O. Palsson	University of California, San Diego	La Jolla	CA

Microgravity and Immunosuppression: A Ground-Based Model in the Slow Turning Lateral Vessel Bioreactor

Dr. Neal R. Pellis	NASA Johnson Space Center (JSC)	Houston	TX

Isolation of the Flow, Growth and Nucleation Rate, and Microgravity Effects on Protein Crystal Growth

Dr. Marc L. Pusey	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Microgravity Crystallization of Avian Egg White Ovostatin

Dr. Marc L. Pusey	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Stem Cell Expansion in Rotating Bioreactors

Dr. Peter J. Quesenberry	University of Massachusetts	Worcester	MA

Study of Crystallization and Solution Properties of Redesigned Protein Surfaces

Prof. David C. Richardson	Duke University Medical Center	Durham	NC

Convective Flow Effects on Protein Crystal Growth and Diffraction Resolution

Prof. Franz E. Rosenberger	University of Alabama, Huntsville	Huntsville	AL

Nucleation and Convection Effects in Protein Crystal Growth

Prof. Franz E. Rosenberger	University of Alabama, Huntsville	Huntsville	AL

Enhancement of Cell Function in Culture by Controlled Aggregation Under Microgravity Conditions

Prof. W. M. Saltzman	Johns Hopkins University	Baltimore	MD

Culture of Porcine Islet Tissue: Evaluation of Microgravity Conditions

Dr. David W. Scharp	Washington University School of Medicine	St. Louis	MO

Robotic Acquisition and Cryogenic Preservation of Single Crystals of Macromolecules for X-Ray Diffraction

Craig D. Smith, Ph.D.	University of Alabama, Birmingham	Birmingham	AL

Influence of Microgravity Conditions on Gene Transfer Into Expanded Populations of Human Hematopoietic Stem Cells

Dr. F. M. Stewart	University of Massachusetts	Worcester	MA

Mechanisms for Membrane Protein Crystallization: Analysis by Small Angle Neutron Scattering

Dr. David M. Tiede	Argonne National Laboratory	Argonne	IL

Preparation and Analysis of RNA Crystals

Dr. Paul Todd	University of Colorado, Boulder	Boulder	CO

Development of Microflow Biochemical Sensors for Space Biotechnology

Dr. Bruce Towe	Arizona State University	Tempe	AZ

Experimental Studies of Protein Crystal Growth Under Simulated Low Gravity Conditions

Dr. Eugene H. Trinh	Jet Propulsion Laboratory (JPL)	Pasadena	CA

Two-Dimensional Protein Crystallization at Interfaces

Prof. Viola Vogel	University of Washington	Seattle	WA

Automation of Protein Crystallization Experiments: Crystallization by Dynamic Control of Temperature

Dr. Keith B. Ward	Office of Naval Research	Washington	DC

Thermal Optimization of Growth and Quality of Protein Crystals

Dr. John M. Wiencek	University of Iowa	Iowa City	IA

A Rational Approach for Predicting Protein Crystallization

Dr. W. W. Wilson	Mississippi State University	Mississippi State	MS

Search for a Dilute Solution Property to Predict Protein Crystallization

Dr. W. W. Wilson	Mississippi State University	Mississippi State	MS

Phase Shifting Interferometric Analysis of Protein Crystal Growth Boundaries and Convective Flows

Mr. William K. Witherow	NASA Marshall Space Flight Center (MSFC)	Huntville	AL

Characterization of Solvation Potentials Between Small Particles

Dr. Charles F. Zukoski	University of Illinois, Urbana-Champaign	Urbana	IL

COMBUSTION

Overview

The Microgravity Combustion Research Program currently includes research in the areas of Premixed Gas Flames, Gaseous Diffusion Flames, Droplet/Spray Combustion, Surface Combustion, Smoldering, and Combustion Synthesis. In addition, a number of advanced diagnostic instrumentation technologies are being developed for various experimental studies in the limited confines available for most microgravity experiments.

In the area of premixed gas combustion, NASA supports experimental and modeling studies of the effects of gravity on flammability limits, flame stability and extinction, low-flow turbulent flames, and laminar flame structure and shape. Modeling activities include simplified analytical approaches aimed at elucidating mechanisms and detailed numerical analysis aimed at quantifying them. To date, several discoveries, all important to hazard control and basic combustion science and made possible only via microgravity experiments, have been made in this area. Activities in the area of gaseous diffusion flames include study of the effects of gravity on soot formation, relationships between chemical kinetic time scales and flow time scales, flammability limits and burning rates, and structure of gas-jet diffusion flames.

In the area of combustion of fuel droplets, particles, and sprays, research includes examining combustion of single-component and multicomponent spherical droplets as well as ordered arrays of fuel droplets and of sprays for improved understanding of the interactions of combustion of individual droplets in sprays. Several new droplet combustion phenomena have been revealed in drop tower microgravity testing; these are expected to lead to major improvements in design of combustors utilizing liquid fuels.

In addition, NASA supported several experimental and analytical studies of the spread of flames across solid and liquid fuel surfaces, both in quiescent oxidizer environments and with low velocity flows; benefits here lie mainly in the area of fire safety. Experimental and analytical studies of smoldering combustion which should have significant impact on prevention of unwanted fires, both on the ground and in space are also supported.

A relatively new area of combustion is the combustion synthesis of materials; one subcategory of particular interest is referred to as Self-deflagrating High -temperature Synthesis. Gravity fields can have major impact on this process, through buoyancy-induced flow effects on heat transport processes and through gravity-driven flow of liquid-phase intermediates through a porous solid matrix prior to cool-down/freezing of the product behind the reaction front. Since the crystal morphology of the final product (which strongly affects its properties) tends to be very sensitive to the temperature-time history seen during the passing of the Self-deflagrating High -temperature Synthesis combustion wave, these gravity-dependent effects can have major effects on the product produced.

To date, the work in microgravity combustion has demonstrated major differences in structures of various types of flames from that seen in normal gravity. Besides the practical implications of these results to combustion efficiency (energy conservation), pollutant control (environmental considerations), and flammability (fire safety), these studies establish that better mechanistic understanding of individual processes making up the overall combustion process can be obtained by comparing of results gathered in microgravity and normal gravity tests. Examples of spin-off technologies developed in this program include:

- Under NASA funding, Dr. Joel Silver and co-workers at Southwest Sciences, Inc., developed a High Frequency Modulated Line Absorption Spectroscopy system for the nonintrusive, non-perturbative measurement of methane, water vapor, and temperature in microgravity flames; this technology has been licensed and an ammonia monitor for industrial and electric utility power plants developed and marketed; instruments for other stack gases are currently under development.
- In conducting microgravity experiments on wrinkled laminar flames in the NASA/Lewis drop towers, Dr. Robert Cheng and Dr. Larry Kostiuk of Lawrence

Berkeley Labs discovered that a metal ring placed above the fuel nozzle could stabilize a fuel-lean flame, leading to the capability for burning fuels at air/fuel ratios which result in significant reduction of NOx emissions, of major importance as regards combustion-generated air pollution.

§ Soot and polycyclic aromatic hydrocarbons arise through fuel pyrolysis reactions common to all combustion processes. Several polycyclic aromatic hydrocarbons and soot are known or suspected carcinogenic or mutagenic agents. By using advanced optical diagnostics such as laser-induced fluorescence and laser-induced incandescence, these byproducts may be detected within combustion processes, with determination of the evolution of soot formation proceeding from gaseous molecular fragments to solid carbon-like soot readily visualized. Such data can critically test soot control strategies.

§ Knowledge of the soot concentration in combustion exhaust gases (as from cars or power plants) is important to several devices such as engines or combustors. In other applications involving soot reduction strategies, the spatial distribution of soot, important for assessing mixing processes or flow uniformity, is required. Recently, the applicability of laser-induced incandescence for measuring soot in post-combustion exhaust was demonstrated using laboratory scale chimney designed to simulate a soot-laden exhaust stream.

In response to a Combustion Science NASA Research Announcement, NRA-95-OLMSA-03, released in May 1995, NASA received 110 proposals. It is expected that a total of about 20 projects, 15-17 in the ground-based program, and 3-5 in the flight definition program will be funded in FY 1996.

Meetings, Awards, Publications

The Third International Microgravity Combustion Workshop was held in Cleveland, Ohio, from April 11-13, 1995. This was a very successful meeting with approximately 70 presentations (approximately 10 from international participants, with the remainder from investigators funded by the NASA Microgravity Combustion Science Program) being heard by an audience of about 230 scientists/engineers. At this meeting, each registrant received a Videotape describing the facilities and operational methods employed at NASA's Lewis Research Center for the Microgravity Combustion Program aimed at familiarizing with assets available to program investigators.

NASA participated in the SPACE T95 conference in Japan in October 1995. An overview of the NASA combustion science program was presented. NASA officials also visited Japanese microgravity drop towers at Hokkaido and Nagoya.

Flight Experiments

Although most work to date has been centered on ground-based studies, involving analytical modeling activities and testing in drop towers at NASA's Lewis Research Center and in aircraft flying parabolic trajectories, limited testing has been carried out on Sounding Rockets and the Shuttle. During late 1994 and early 1995, the seventh and eighth flights of the Solid Surface Combustion Experiment were completed for Dr. Robert Altenkirch (Washington State University) during the STS-63 and STS-64 Shuttle missions, with samples of Rplexi-glasS type material being burnt in various oxygen-nitrogen atmospheres under quiescent conditions. Computer image enhancement techniques are being employed to analyze the film records of these experiments, described in more detail in another paper at this meeting, with the images and recorded temperature data being compared with computer simulations of the flame spreading process to provide new insights into the flame spreading process.

Two Sounding Rocket tests on the Spread Across Liquids program of Dr. Howard Ross (Lewis Research Center) were successfully carried out in November 1994 and August 1995. Each flight provided approximately six minutes of microgravity time (during which three experimental burns were accomplished) for investigation of the flame spread characteristics across a deep pool of liquid fuel in a microgravity environment, with particle imaging velocimetry, rainbow schlieren, and flame spread data being obtained for comparison with model predictions.

The Microgravity Smoldering Combustion Experiment of Dr. Carlos Fernandez-Pello, University of California-Berkeley flew for the first time as a Getaway Special Canister payload on the STS-69 Shuttle mission in mid-1995. In addition, an experiment on Dr. Forman WilliamsU (University of California at San Diego) Fiber-Supported Droplet Combustion was carried out in the Shuttle Glovebox on the Second United States Microgravity Laboratory mission in September 1995.

Three other Glovebox investigations: Forced Flow Flame Spreading Test, Comparative Soot Diagnostics, and Radiative Ignition and Transition to Flame Spread Investigation are scheduled for flight on the Third United States Microgravity Payload in early 1996. Major efforts are also being expended on the development of flight hardware for Dr. WilliamsU Droplet Combustion Experiment, Dr. Paul Ronney's (University of Southern California) Study of Flameballs at Low Lewis Numbers Experiment, and Dr. Gerard Faeth's (University of Michigan) Laminar Soot Processes in Flames Experiment all scheduled to fly on Microgravity Spacelab-1 in early 1997. In addition, Dr. Yousef Bahadori's Turbulent Gas Jet Diffusion Flame experiment is tentatively scheduled to go to flight in mid-1996.

The FY 1995 ground and flight tasks for combustion science are listed in Table 4.2.

Table 4.2 Combustion Science Tasks Funded by MSAD in FY 1995

Flight Experiments

Scientific Support for an Orbiter Middeck Experiment on Solid Surface Combustion

Prof. Robert A. Altenkirch	Washington State University	Pullman	WA

Low-Velocity, Opposed-Flow Flame Spread in a Transport-Controlled, Microgravity Environment

Prof. Robert A. Altenkirch	Washington State University	Pullman	WA

Reflight of the Solid Surface Combustion Experiment with Emphasis on Flame Radiation Near Extinction

Prof. Robert A. Altenkirch	Washington State University	Pullman	WA

Gravitational Effects On Laminar, Transitional, and Turbulent Gas-Jet Diffusion Flames

Dr. M. Y. Bahadori	Science Applications International Corporation (SAIC)	Torrance	CA

Sooting Effects in Reduced Gravity Droplet Combustion (SEDC)

Prof. Mun Y. Choi	University of Illinois, Chicago	Chicago	IL

Candle Flames in Microgravity

Dr. Daniel L. Dietrich	NASA Lewis Research Center (LeRC)	Cleveland	OH

Investigation of Laminar Jet Diffusion Flames in Microgravity: A Paradigm for Soot Processes in Turbulent Flames

Prof. Gerard M. Faeth	University of Michigan	Ann Arbor	MI

Unsteady Diffusion Flames: Ignition, Travel, and Burnout

Dr. Frank Fendell	TRW	Redondo Beach	CA

Fundamental Study of Smoldering Combustion in Microgravity

Prof. A. C. Fernandez-Pello	University of California, Berkeley	Berkeley	CA

Ignition and the Subsequent Transition to Flame Spread in Microgravity

Dr. Takashi Kashiwagi	National Institute of Standards and Technology (NIST)	Gaithersburg	MD

Studies of Premixed Laminar and Turbulent Flames at Microgravity

Prof. Paul D. Ronney	University of Southern California	Los Angeles	CA

Ignition and Flame Spread of Liquid Fuel Pools

Dr. Howard D. Ross	NASA Lewis Research Center (LeRC)	Cleveland	OH

Combustion of Solid Fuel in Very Low Speed Oxygen Streams

Prof. James S. T'ien	Case Western Reserve University	Cleveland	OH

Droplet Combustion Experiment

Prof. Forman A. Williams	University of California, San Diego	La Jolla	CA

Ground Experiments

Effects of Energy Release on Near Field Flow Structure of Gas Jets

Prof. Ajay K. Agrawal	University of Oklahoma	Norman	OK

Radiative Extinction of Diffusion Flames

Prof. Arvind Atreya	University of Michigan	Ann Arbor	MI

Multicomponent Droplet Combustion in Microgravity: Soot Formation, Emulsions, Metal-Based Additives, and the Effect of Initial Droplet Diameter

Prof. C. T. Avedisian	Cornell University	Ithica	NY

Development of Advanced Diagnostics for Characterization of Burning Droplets in Microgravity

Dr. William D. Bachalo	Aerometrics, Inc.	Sunnyvale	CA

Ignition and Combustion of Bulk Metals

Prof. Melvyn C. Branch	University of Colorado, Boulder	Boulder	CO

Ignition and Combustion of Bulk Metals in Microgravity (Ground-Based Experiment)

Prof. Melvyn C. Branch	University of Colorado, Boulder	Boulder	CO

Modeling of Microgravity Combustion Experiments - Phase II

Prof. John D. Buckmaster	University of Illinois, Urbana-Champaign	Urbana	IL

Buoyancy Effects on the Structure and Stability of Burke-Schumann Diffusion Flames

Prof. L.- D. Chen	University of Iowa	Iowa City	IA

Gravitational Effects on Premixed Turbulent Flames

Dr. Robert K. Cheng	Lawrence Berkeley Laboratory	Berkeley	CA

Gravitational Effects on Premixed Turbulent Flames: Microgravity Flame Structures

Dr. Robert K. Cheng	Lawrence Berkeley Laboratory	Berkeley	CA

Combustion of Interacting Droplet Arrays in a Microgravity Environment

Dr. Daniel L. Dietrich	NASA Lewis Research Center (LeRC)	Cleveland	OH

Internal and Surface Phenomena in Heterogeneous Metal Combustion

Dr. Edward L. Dreizin	AeroChem Research Laboratories, Inc.	Princeton	NJ

Flame-Vortex Interactions Imaged in Microgravity

Prof. James F. Driscoll	University of Michigan	Ann Arbor	MI

Aerodynamic, Unsteady, Kinetic, and Heat Loss Effects on the Dynamics and Structure of Weakly-Burning Flames in Microgravity

Prof. Fokion N. Egolfopoulos	University of Southern California	Los Angeles	CA

Effects of Gravity on Sheared and Nonsheared Turbulent Nonpremixed Flames

Prof. Said E. Elghobashi	University of California, Irvine	Irvine	CA

Combustion of Electrostatic Sprays of Liquid Fuels in Laminar and Turbulent Regimes

Prof. Alessandro Gomez	Yale University	New Haven	CT

Three-Dimensional Flow in a Microgravity Diffusion Flame

Prof. Jean R. Hertzberg	University of Colorado, Boulder	Boulder	CO

Unsteady Numerical Simulations of the Stability and Dynamics of Flames in Microgravity

Dr. K. Kailasanath	Naval Research Laboratory (NRL)	Washington	DC

Sooting Turbulent Jet Diffusion Flames

Prof. Jerry C. Ku	Wayne State University	Detroit	MI

Soot and Radiation Measurements in Microgravity Turbulent Jet Diffusion Flames

Prof. Jerry C. Ku	Wayne State University	Detroit	MI

Studies of Flame Structure in Microgravity

Prof. Chung K. Law	Princeton University	Princeton	NJ

Chemical Inhibitor Effects on Diffusion Flames in Microgravity

Dr. Gregory T. Linteris	National Institute of Standards and Technology (NIST)	Gaithersburg	MD

Structure and Dynamics of Diffusion Flames in Microgravity

Prof. Moshe Matalon	Northwestern University	Evanston	IL

Filtration Combustion for Microgravity Applications: (1) Smoldering, (2) Combustion Synthesis of Advanced Materials

Prof. Bernard J. Matkowsky	Northwestern University	Evanston	IL

Combustion of PTFE: The Effect of Gravity on Ultrafine Particle Generation

Prof. J. T. McKinnon	Colorado School of Mines	Golden	CO

Premixed Turbulent Flame Propagation in Microgravity

Prof. Suresh Menon	Georgia Institute of Technology	Atlanta	GA

A Fundamental Study of the Combustion Syntheses of Ceramic-Metal Composite Materials Under Microgravity Conditions - Phase II

Prof. John J. Moore	Colorado School of Mines	Golden	CO

Flow and Ambient Atomosphere Effects on Flame Spread at Microgravity

Prof. Paul D. Ronney	University of Southern California	Los Angeles	CA

Combustion Research

Dr. Howard D. Ross	NASA Lewis Research Center (LeRC)	Cleveland	OH

Reduced Gravity Combustion with 2-Component Miscible Droplets

Prof. Benjamin D. Shaw	University of California, Davis	Davis	CA

Quantitative Measurement of Molecular Oxygen in Microgravity Combustion

Dr. Joel A. Silver	Southwest Sciences, Inc.	Sante Fe	NM

Numerical Modeling of Flame-Balls in Fuel-Air Mixtures

Prof. Mitchell D. Smooke	Yale University	New Haven	CT

Interactions Between Flames on Parallel Solid Surfaces

Dr. David L. Urban	NASA Lewis Research Center (LeRC)	Cleveland	OH

Gasless Combustion Synthesis from Elements Under Microgravity: A Study of Structure-Formation Processes

Prof. Arvind Varma	University of Notre Dame	Nortre Dame	IN

Studies of Wind-Aided Flame Spread Over Thin Cellulosic Fuels in Microgravity

Prof. Indrek S. Wichman	Michigan State University	East Lansing	MI

High Pressure Droplet Combustion Studies

Prof. Forman A. Williams	University of California, San Diego	La Jolla	CA

High-Pressure Combustion of Binary Fuel Sprays

Prof. Forman A. Williams	University of California, San Diego	La Jolla	CA

Laser Diagnostics for Fundamental Microgravity Droplet Combustion Studies

Dr. Michael Winter	United Technologies Research Center	East Hartford	CT

Combustion of a Polymer (PMMA) Sphere in Microgravity

Dr. Jiann C. Yang	National Institute of Standards and Technology (NIST)	Gaithersburg	MD

FLUID PHYSICS

Overview

The primary objective of the microgravity fluid physics program is to conduct a comprehensive research program on fluid dynamics and transport phenomena where fundamental behavior is limited or affected by the presence of gravity, and where low-gravity experiments allow insight into that behavior. For example, a low-gravity environment results in greatly reduced density-driven convection flows and allows the study of other forms of convection such as flows driven by magneto/electrodynamics, surface tension gradients, or other interfacial phenomena. Investigations of these phenomena result in the basic scientific and practical knowledge needed to design effective and reliable space-based systems and facilities that rely on fluid processes. Another objective of the fluid physics program is to assist other microgravity disciplines, such as materials science or combustion science, by developing an understanding of the gravity-dependent fluid phenomena that underlie their experimental observations. The fluid physics program continued to make major advances in FY 1995. The fluid physics NASA Research Announcement released in the fall of 1994, which included both fluid physics and low-temperature microgravity physics, generated more than 354 proposals. External peer review panels evaluated 251 of these proposals in the area of fluid physics in November 1995, with NASA ultimately accepting 84 proposals for funding.

A NASA partnership with NIH is using laser light scattering to detect early signs of the onset of cataract formation; discussions with managers from the National Eye Institute have led to the decision to proceed with development of a prototype diagnostic tool. After successful demonstration, the National Eye Institute is interested in obtaining the technology for use in a large scale clinical trial. Work at NASA's Lewis Research Center demonstrated a capability for measurement of the size distribution of a protein in the eye that is related to the early development stages of cataracts. The NASA microgravity research program is also collaborating with researchers at the National Eye Institute using protein crystal growth technology to determine the structures of important proteins related to the signal pathway for sight.

Scientists at NASA's Lewis Research Center developed a Stereo Imaging Velocimetry system for fluid physics experiments that is now being used by LTV Steel to study fluid flow for LTV's continuous casting processes. LTV requested NASA assistance in measuring velocities and flow patterns in their scale water models of the submerged entry nozzle and mold of a continuous casting machine, with an ultimate goal of developing new nozzle designs and casting practices to optimize flow in the mold and reduce flow induced defects in as-cast slabs.

Professor Jungho Kim at the University of Denver, as part of his microgravity program sponsored research on boiling heat transfer, developed a microscale heater using technologies adapted from integrated circuit fabrication. This device offers scientists studying the process of boiling new insights into the detailed physical mechanisms by which bubbles form, grow, and depart from heater surfaces. The long-term goal of the research is to contribute to more efficient and reliable heat transfer technologies for applications both on Earth and in space.

At the University of Colorado, Prof. Noel Clark reported obtaining the first unambiguous evidence for longitudinal ferroelectricity in a liquid crystal. His team obtained this result in a freely suspended film of an antiferroelectric liquid crystal material. This discovery will enable the first measurement of longitudinal polarization and a detailed comparison of longitudinal and transverse liquid crystal polarization.

Professor Hallinan, of the University of Dayton, showed that surface tension driven flows can enhance the heat transfer effectiveness of devices that rely on evaporative phase change. His experiments examined use of a binary mixture of pentane and decane, a non-volatile solute, as the working fluid and demonstrated that addition of about 1.5% decane significantly enhanced the heat transport relative to pure pentane. This procedure also increased the stability of the interfacial film producing a more steady heat transfer performance.

Meetings, Awards, Publications

Dr. Harold Swinney, fluid physics principal investigator and a member of the Microgravity Fluid Physics Discipline Working Group, was selected as the 1995 recipient of the American Physical Society Fluid Dynamics Prize. Professor Swinney's efforts were the first to bridge the gap between nonlinear dynamic systems theory and laboratory investigations. Dr. Swinney currently holds the Sid Richardson Foundation Regents Chair in Physics at the University of Texas at Austin.

Prof. Eric W. Kaler, a principal investigator in the area of fluid physics from the University of Delaware, won the 1995 Curtis McGraw award, a national award for engineering work for those under 40 years old, for "research excellence" from the American Association for Engineering Education.

Professor Gareth McKinley of Harvard University was honored with the 1994 British Society of Rheology Annual Award in April 1995 in Wales, Great Britain, for his contributions to the field of Non-Newtonian Rheology.

Flight Experiments

The Second United States Microgravity Laboratory had several fluid physics experiments on board. Dr. Taylor Wang of Vanderbilt University examined two new aspects of drop phenomena: the fissioning of rotating drops and the centering mechanism in shell drops. Dr. Wang used the Drop Physics Module, a rectangular chamber where samples are positioned and manipulated by sound waves and levitated acoustically, to test mathematical theories that describe the physics of fissioning atoms. Dr. Wang also studied shell drops (drops with one large bubble inside) that may have future applications for medicine.

Dr. Robert Apfel of Yale University used the Drop Physics Module to study the influence of surfactants (substances that migrate toward the free surfaces of liquids and reduce surface tension) on the behavior of drops. Dr. John Hart of the University of Colorado used his Geophysical Fluid Flow Cell to gain new insights into atmospheric thermal convection currents. Dr. Simon Ostrach of Case Western University used the Surface Tension Driven Convection Experiment apparatus to examine thermocapillary flows, which are obscured by gravity on Earth. Dr. Ostrach successfully observed and characterized the transition from steady to time-dependent flow that has been of substantial controversy in the fluid dynamics community and of great interest to crystal growers who use the floating zone process. Glovebox experiments conducted on the Second United States Microgravity Laboratory included the Colloidal Disorder-Order Transition experiment, the Interface Configuration Experiment, and the Oscillatory Thermocapillary Flow experiment.

The FY 1995 ground and flight tasks for fluid physics are listed in Table 4.3.

Table 4.3 Fluid Physics Tasks Funded by MSAD in FY 1995

Flight Experiments

Surface Controlled Phenomena			
Prof. Rober E. Apfel	Yale University	New Haven	CT
Critical Viscosity of Xenon			
Dr. Robert F. Berg	National Institute of Standards and Technology (NIST)	Gaithersburg	MD
The Dynamics of Disorder-Order Transitions in Hard Sphere Colloidal Dispersions			
Prof. Paul M. Chaikin	Princeton University	Princeton	NJ
Critical Dynamics of Fluids			
Prof. Richard A. Ferrell	University of Maryland	College Park	MD
Microscale Hydrodynamics Near Moving Contact Lines			
Prof. Stephen Garoff	Carnegie Mellon University	Pittsburgh	PA
Geophysical Fluid Flow Cell			
Dr. John E. Hart	University of Colorado, Boulder	Boulder	CO

Interfacial Phenomena in Multilayered Fluid Systems

Prof. Jean N. Koster	University of Colorado, Boulder	Boulder	CO

Extensional Rheology of Non-Newtonian Materials

Prof. Gareth H. McKinley	Harvard University	Cambridge	MA

Pool Boiling Experiment

Prof. Herman Merte, Jr.	University of Michigan	Ann Arbor	MI

Surface Tension-Driven Convection Experiment (STDCE-1, STDCE-2)

Prof. Simon Ostrach	Case Western Reserve University	Cleveland	OH

Modeling and New Experiment Definition for the VIBES

Prof. Robert L. Sani	University of Colorado, Boulder	Boulder	CO

Studies in Electrohydrodynamics

Dr. Dudley A. Saville	Princeton University	Princeton	NJ

Mechanics of Granular Materials

Dr. Stein Sture	University of Colorado, Boulder	Boulder	CO

Thermocapillary Migration and Interactions of Bubbles and Drops

Prof. R. S. Subramanian	Clarkson University	Potsdam	NY

Drop Dynamics Investigation

Prof. Taylor G. Wang	Vanderbilt University	Nashville	TN

Physics of Colloid in Space

Dr. David A. Weitz	University of Pennsylvania	Philadelphia	PA

Ground Experiments

Study of Two-Phase Flow and Heat Transfer in Reduced Gravities

Dr. Davood Abdollahian	S. Levy, Inc.	Campbell	CA

Colloids & Nucleation

Prof. Bruce J. Ackerson	Oklahoma State University	Stillwater	OK

Stability Limits and Dynamics of Nonaxisymmetric Liquid Bridges

Prof. J. Iwan D. Alexander	University of Alabama, Huntsville	Huntsville	AL

Investigations of Multiple-Layer Convection

Prof. C. D. Andereck	Ohio State University	Columbia	OH

Electrokinetic Transport of Heterogeneous Particles in Suspensions

Prof. John L. Anderson	Carnegie Mellon University	Pittsburgh	PA

Experimental Study of Liquid Jet Impingement in Microgravity: The Hydraulic Jump

Prof. C. T. Avedisian	Cornell University	Ithica	NY

Studies on the Response of Emulsions to Externally-Imposed Electric and Velocity Fields: Electrohydrodynamic Deformation and Interaction of a Pair of Drops

Prof. James C. Baygents	University of Arizona	Tucson	AZ

Marangoni Effects in Boiling of Binary Fluid Mixtures Under Microgravity

Prof. Van P. Carey	University of California, Berkeley	Berkeley	CA

Marangoni Instability Induced Convection in Evaporating Liquid Droplets

Dr. An-Ti Chai	NASA Lewis Research Center (LeRC)	Cleveland	OH

Rewetting of Monogroove Heat Pipe in Space Station Radiators

Prof. S. H. Chan	University of Wisconsin, Milwaukee	Milwaukee	WI

Marangoni and Double-Diffusive Convection in a Fluid Layer Under Microgravity

Prof. Chuan F. Chen	University of Arizona	Tucson	AZ

Transport Phenomena in Stratified Flow in the Presence and Absence of Gravity

Prof. Norman Chigier	Carnegie Mellon University	Pittsburgh	PA

Bubble Dynamics, Two-Phase Flow, and Boiling Heat Transfer in Microgravity

Prof. Jacob N. Chung	Washington State University	Pullman	WA

Reactive Fluids Experiment: Chemical Vapor Deposition

Dr. Ivan O. Clark	NASA Langley Research Center (LaRC)	Hampton	VA

Microgravity Particle Dynamics

Dr. Ivan O. Clark	NASA Langley Research Center (LaRC)	Hampton	VA

Studies of Freely Suspended Liquid Crystal Bubbles

Prof. Noel A. Clark	University of Colorado, Boulder	Boulder	CO

Fluid Interface Behavior Under Low- and Reduced-Gravity Conditions

Prof. Paul Concus	University of California, Berkeley	Berkeley	CA

Convection and Morphological Stability During Directional Solidification

Dr. Sam R. Coriell	National Institute of Standards and Technology (NIST)	Gaithersburg	MD

Microphysics of Close Approach and Film Drainage and Rupture During Drop Coalescence

Prof. Robert H. Davis	University of Colorado, Boulder	Boulder	CO

Phase Segregation Due to Simultaneous Migration and Coalescence

Prof. Robert H. Davis	University of Colorado, Boulder	Boulder	CO

Interaction and Aggregation of Colloidal Biological Particles and Droplets in Electrically-Driven Flows

Prof. Robert H. Davis	University of Colorado, Boulder	Boulder	CO

Theory of Solidification

Prof. Stephen H. Davis	Northwestern University	Evanston	IL

Microgravity Foam Structure and Rheology

Prof. Douglas J. Durian	University of California, Los Angeles	Los Angeles	CA

The Influence of Gravity on Nucleation, Growth, Stability and Structure in Ordering Soft-Spheres			
Prof. Alice P. Gast	Stanford University	Stanford	CA
Plasma Dust Crystallization			
Prof. John A. Goree	University of Iowa	Iowa City	IA
Fluid Mechanics of Capillary Elastic Instabilities in the Microgravity Environment			
Prof. James B. Grotberg	Northwestern University	Evanston	IL
Effects of Convection on the Thermocapillary Motion of Deformable Drops			
Prof. Hossein Haj-Hariri	University of Virginia	Charlottesville	VA
Evaporation from a Meniscus within a Capillary Tube in Microgravity			
Prof. Kevin P. Hallinan	University of Dayton	Dayton	OH
Interfacial Transport and Micellar Solubilization Processes			
Prof. T. A. Hatton	Massachusetts Institute of Technology (MIT)	Cambridge	MA
Critical Phenomena, Electrodynamics, and Geophysical Flows			
Dr. John Hegseth	University of New Orleans	New Orleans	LA
Nonlinear, Resonance-Controlled Bifurcation Structure of Oscillating Bubbles			
Dr. R G. Holt	Jet Propulsion Laboratory (JPL)	Pasadena	CA
Thermocapillary Instabilities and g-Jitter Convection			
Prof. George M. Homsy	Stanford University	Stanford	CA
Turbidity of a Binary Mixture Very Close to the Critical Point			
Prof. Donald T. Jacobs	The College of Wooster	Wooster	OH
Kinetic and Transport Phenomena in a Microgravity Environment			
Prof. David Jasnow	University of Pittsburgh	Pittsburgh	PA
Surfactant-Based Critical Phenomena in Microgravity			

Prof. Eric W. Kaler	University of Delaware	Newark	DE

Instability of Velocity and Temperature Fields in the Vicinity of a Bubble on a Heated Surface

Dr. Mohammad Kassemi	Ohio Aerospace Institute	Cleveland	OH

Stabilization of Thermocapillary Convection by Means of Nonplanar Flow Oscillations

Prof. Robert E. Kelly	University of California, Los Angeles	Los Angeles	CA

Microgravity Heat Transfer Mechanisms in the Nucleate Pool Boiling and Critical Heat Flux Regimes Using a Novel Array of Microscale Heaters

Prof. Jungho Kim	University of Denver	Denver	CO

Molecular Dynamics of Fluid-Solid Systems

Prof. Joel Koplik	City College of New York	New York	NY

Fluid Dynamics and Solidification of Metallic Melts (FDSMM)

Prof. Jean N. Koster	University of Colorado, Boulder	Boulder	CO

Thermocapillary Convection in Floating Zones under Simulated Reduced Gravity

Prof. Sindo Kou	University of Wisconsin, Madison	Madison	WI

Analysis of Phase Distribution Phenomena in Microgravity Environments

Prof. Richard T. Lahey	Rensselaer Polytechnic Institute	Troy	NY

Nonlinear Drop Dynamics and Chaotic Phenomena

Dr. L. G. Leal	University of California, Santa Barbara	Santa Barbara	CA

Oscillatory Cross-Flow Electrophoresis: Application to Production Scale Separations

Dr. David T. Leighton	University of Notre Dame	South Bend	IN

Low Dimensional Models for Thermocapillary Convective Flows in Crystal Growth Processes

Prof. A. Liakopoulos	Lehigh University	Bethlehem	PA

Absolute and Convective Instability of a Liquid Jet at Microgravity

Prof. Sung P. Lin	Clarkson University	Potsdam	NY

Magnetorheological Fluids in Microgravity

Prof. Jing Liu	California State University, Long Beach	Long Beach	CA

Cross Effects in Microgravity Flows

Prof. Sudarshan K. Loyalka	University of Missouri, Columbia	Columbia	MO

Controlling the Mobility of a Fluid Particle in Space by Using Remobilizing Surfactants

Prof. Charles Maldarelli	City University of New York	New York	NY

Stabilization and Low Frequency Oscillations of Capillary Bridges with Modulated Acoustic Radiation Pressure

Prof. Philip L. Marston	Washington State University	Pullman	WA

Study of Disturbances in Fluid-Fluid Flows in Open and Closed Systems

Prof. Mark J. McCready	University of Notre Dame	Notre Dame	IN

Study of Forced Convection Nucleate Boiling in Microgravity

Prof. Herman Merte, Jr.	University of Michigan	Ann Arbor	MI

Control of Oscillatory Thermocapillary Convection in Microgravity

Prof. G. P. Neitzel	Georgia Institute of Technology	Atlanta	GA

Industrial Processes

Prof. Simon Ostrach	Case Western Reserve University	Cleveland	OH

Marangoni Effects on the Bubble Dynamics in a Pressure Driven Flow

Prof. Chang-Won Park	University of Florida	Gainesville	FL

Nonlinear Dynamics and Nucleation Kinetics in Near-Critical Liquids

Prof. Alexander Z. Patashinski	Northwestern University	Evanston	IL

Two-Phase Interfaces in Weak External Fields.

Prof. Jerome K. Percus	New York University	New York	NY

Containerless Capillary Wave Turbulence

Dr. Seth J. Putterman	University of California, Los Angeles	Los Angeles	CA

Studies of Radiation-Driven and Buoyancy-Driven Fluid Flows and Transport

Prof. Paul D. Ronney	University of Southern California	Los Angeles	CA

Fluid Creep Effects on Near-Wall Solute Transport for Non-Isothermal Ampoules and Suspended Particle Transport Coefficients

Prof. Daniel E. Rosner	Yale University	New Haven	CT

Gas Flow from Porous Media and Microgravity Battery Spills

Dr. Robert T. Ruggeri	Boeing Company	Seattle	WA

Ground Based Studies of Thermocapillary Flows in Levitated Drop

Prof. Satwindar S. Sadhal	University of Southern California	Los Angeles	CA

Effects of Gravity and Shear on the Dynamics and Stability of Particulate and Multiphase Flows

Prof. Ashok S. Sangani	Syracuse University	Syracuse	NY

Dielectric and Electrohydrodynamic Properties of Suspensions

Dr. Dudley A. Saville	Princeton University	Princeton	NJ

Electrohydrodynamic Pool Boiling in Reduced Gravity

Prof. Benjamin D. Shaw	University of California, Davis	Davis	CA

Transport Processes Research

Dr. Bhim S. Singh	NASA Lewis Research Center (LeRC)	Cleveland	OH

Solute Nucleation and Growth in Supercritical Fluid Mixtures

Dr. Gregory T. Smedley	California Institute of Technology	Pasadena	CA

Behavior of Unsteady Thermocapillary Flows

Prof. Marc K. Smith	Georgia Institute of Technology	Atlanta	GA

Flow-Influenced Shape Stability: Breakup in Low Gravity

Prof. Paul H. Steen	Cornell University	Ithaca	NY

Interactions of Bubbles and Drops in a Temperature Gradient

Prof. R. S. Subramanian	Clarkson University	Potsdam	NY

Instability in Surface-Tension-Driven Benard Convection

Prof. Harry L. Swinney	University of Texas, Austin	Austin	TX

Crystal Growth and Fluid Mechanics Problems in Directional Solidification

Prof. Saleh Tanveer	Ohio State University	Columbus	OH

Oscillatory/Chaotic Thermocapillary Flow Induced by Radiant Heating

Dr. Robert L. Thompson	NASA Lewis Research Center (LeRC)	Cleveland	OH

Light Scattering Studies of Relative Motions of Solid Particles in Turbulent Flows

Prof. Penger Tong	Oklahoma State University	Stillwater	OK

Computational Studies of Drop Collision and Coalescence

Prof. Gritar Tryggvason	University of Michigan	Ann Arbor	MI

Nonlinear Bubble Interactions in Acoustic Pressure Fields

Prof. John Tsamopoulos	State University of New York, Buffalo	Buffalo	NY

Residual Accelerations in a Microgravity Environment

Prof. Jorge Viqals	Florida State University	Tallahassee	FL

Experimental Study of the Vapor Bubble Thermosyphon

Prof. Peter C. Wayner, Jr.	Rensselaer Polytechnic Institute	Troy	NY

Study of Two Phase Flow Dynamics and Heat Transfer at Reduced Gravity

Prof. Larry Witte	University of Houston	Houston	TX

Interactions Between Solidification and Compositional Convection in Alloys

Prof. M. G. Worster	Northwestern University	Evanston	IL

Nucleation and Chiral Symmetry Breaking under Hydrodynamic Flows

Dr. Xiao-lun Wu	University of Pittsburgh	Pittsburgh	PA

Oscillatory Thermocapillary Convection

Prof. Abdelfattah Zebib	Rutgers University	Piscataway	NJ

MATERIALS SCIENCE

Overview

One of the goals of materials science is to study how materials form and how the forming process controls a material's properties. By careful modeling and experimentation, the mechanisms by which materials are formed can be better understood, and processing controls better designed and improved. In this way, materials scientists can design new metal alloys, semiconductors, ceramics, glasses, and polymers to improve the performance of a wide range of products.

The production processes for most materials includes steps that are very heavily influenced by the force of gravity. The opportunity to observe, monitor and study these processes in low gravity promises to increase our fundamental understanding of production processes and of their effects on the properties of the materials produced. Scientists will use these insights from low gravity and space research to improve and control the properties of materials ranging from glass and steel to semiconductors and plastics.

The goal of the microgravity materials science program during FY 1995 was to process materials under reduced gravity conditions to seek and understand quantitatively the cause and effect relationships between the processing, the structure and the properties of materials. Of particular interest was understanding the role of gravity-driven convection in the processing of such materials and polymers. Highlights of FY 1995 research include:

- Based on his orbital research, the late Dr. Julian Szekely of the Massachusetts Institute of Technology developed new mathematical techniques to model the behavior of molten metals. These techniques have been used by the metals and semiconductor industries to design equipment and to improve predictions of the behavior of metals during processing.
- Professor William Krantz of the University of Colorado at Boulder conducted experiments aboard NASA's KC-135 parabolic flight aircraft that have served to isolate the role of gravity in the formation of defects (macrovoids) during membrane casting. The results of this work not only provide new and

fundamental insight into this important problem in materials science, these results have led to the development of a modified terrestrial (earth based) process that eliminates the formation of these types of defects. Membranes with fewer macrovoids would have important applications in the areas of dialysis, filtration and separation.

§ Dr. Martin Glicksman, Rensselaer Polytechnic Institute, directed experiments aboard the Second United States Microgravity Payload which produced groundbreaking new insights into how the structure of metal forms. Results of his experiment will aid in the development of stronger or more corrosion resistant metal alloys. Further experiments are planned for the Third United States Microgravity Payload, scheduled for launch in February 1996.

In response to the FY 1995 Materials Science NASA Research Announcement, NASA reviewed 207 proposals; final funding decisions will be made early in FY 1996.

Meetings, Awards, Publications

The Fifth Eastern Regional Conference on Crystal Growth was held in Atlantic City, New Jersey, from October 4-7, 1994. Twelve microgravity- related papers were presented. Martin Glicksman, a principal investigator in the materials science discipline, chaired the program committee.

The Ninth International Summer School on Crystal Growth was held from June 11-16, 1995 at the National Sports Center, Papendalin, the Netherlands. The school, geared towards scientists who expect crystal growth to become an essential part of their research, focused on the fundamental and applied crystal growth areas. Dr. Iwan D. Alexander (University of Alabama at Huntsville), a principal investigator in the materials science discipline, was among the scientists who conducted sessions at the school.

The Eleventh International Conference on Crystal Growth convened in the Netherlands from June 18-23, 1995. Symposia topics included theoretical research and experimental investigations in model systems of crystals and their surfaces and the ambient phase.

Materials science researchers were also well represented at the Gordon Research Conference on Gravitational Effects on Physio-Chemical Systems held in Henniker, New Hampshire, in July 1995.

The American Association for the Advancement of Science awarded its first prize for best student paper to Sanjay Konagurthu for his materials science work to isolate the role of gravity in the formation of defects during membrane casting. Konagurthu conducted his research in conjunction with NASA materials science principal investigator Professor William Krantz (University of Colorado at Boulder).

Flight Experiments

The successful processing of the samples in the Crystal Growth Furnace in the First United States Microgravity Laboratory mission led to an additional opportunity for the same experimenters to elaborate on and refine the work done on that mission. Two of these experiments used the directional solidification method in which the furnace is slowly translated along the sample, allowing the molten material to gradually cool from one end to the other. This permits the material to grow as a single crystal from a seed crystal which is not melted. The third experiment used the vapor transport technique in which the sample is heated so that it sublimes from a solid to a gas; the vaporized material then diffuses into a cooler area of the apparatus where it condenses onto a seed crystal, with a layer of material being built up on this seed crystal. Near the end of the mission, a fourth sample was processed in the furnace to examine the growth of well understood model material under clearly defined and controlled gravity conditions. Two samples were grown, one with the residual gravity (or residual acceleration vector) in the best available orientation, and the second with a slowly varying vector.

For the Second United States Microgravity Laboratory mission, the Crystal Growth Furnace was significantly modified to incorporate Current Pulse Interface Demarcation. This technology allows a direct current of controlled time and amplitude to be pulsed through the sample at pre-determined times during the processing. This current has a small but detectable effect on the structure of the material, but has little effect on the stabilized growth conditions. Post-growth processing of the sample can delineate the effect of the current pulsing and enable the experimenter to determine the position and shape of the liquid-solid boundary throughout the solidification process. Thus a complete temporal history of the solidification of the material can be ascertained and the dynamics of solidification of material produced under low gravity conditions can be carefully compared with that produced under normal gravity.

Prof. David J. Larson Jr., of the State University of New York at Stonybrook continued the investigation titled ROrbital Processing of High Quality Cadmium Zinc Telluride Compound Semiconductors,S an experiment examining the effects of gravity on the growth and quality of alloyed compound semiconductors in an attempt to produce high quality cadmium zinc telluride crystals with fewer physical defects and more uniform distribution of chemical components than those grown on Earth. By studying space-grown crystals, Dr. Larson and his research team can identify the role of gravity in causing structural defects in the crystal system. An ultimate goal is prediction of the distribution of chemical components within a crystal, important information for improving crystal growth technology on Earth.

The Study of Dopant Segregation Behavior During the Crystal Growth of Gallium Arsenide in Microgravity experiment investigated techniques for uniformly distributing a small amount of selenium within a gallium arsenide crystal as it grows in microgravity. Growing the crystals in microgravity greatly reduces the gravitational influences that cause an un- even distribution of dopants in crystals grown on Earth. This allowed Dr. Matthiesen (the Principal Investigator) to identify more subtle influences, either confirming or denying the theories and models used to describe crystal growth on Earth. For the Second United States Microgravity Laboratory mission experiment, the growing crystals were marked every 100 to 300 seconds by electric pulsing using time-coded Current Pulse Interface Demarcation to reveal the microscopic growth rate of the crystal and the shape and location of the liquid/solid boundary, or interface, at various stages of growth.

The Second United States Microgravity Laboratory mission experiment Vapor Transport Crystal Growth of Mercury Cadmium Telluride in Microgravity experiment focused on the initial phase of vapor crystal growth in a complex alloy semiconductor. Dr. Herbert Wiedemeier and his team grew a crystalline layer of mercury cadmium telluride on a cadmium telluride substrate, or base, by the vapor crystal growth method which caused layers, or thin films, of mercury cadmium telluride to be grown on the substrate in a process called epitaxial layer growth. The resulting crystal will be analyzed to determine the effect of microgravity on the growth rate, chemical composition structural characteristics and other properties of the initial crystalline layer (determinant of subsequent atomic arrangement of the entire crystal that forms on the substrate). Performance of infrared detectors made from this material will be greatly improved when electronics manufacturers can grow crystals without structural flaws and with more uniform distribution of chemical components; better understanding of this crystal growth method will enhance ground based production of similar semiconductor materials.

The FY 1995 ground and flight tasks for materials science are listed in Table 4.4.

Table 4.4 Materials Science Tasks Funded by MSAD in FY 1995

Flight Experiments

In Situ Monitoring of Crystal Growth Using MEPHISTO			
Dr. Reza Abbaschian	University of Florida	Gainesville	FL
Coupled Growth in Hypermonotectics			
Dr. J. B. Andrews	University of Alabama, Birmingham	Birmingham	AL
Effects on Nucleation by Containerless Processing			
Prof. Robert J. Bayuzick	Vanderbilt University	Nashville	TN
Alloy Undercooling Experiments in Microgravity Environment			
Prof. Merton C. Flemings	Massachusetts Institute of Technology (MIT)	Cambridge	MA
Compound Semiconductor Growth in Low-g Environment			
Dr. Archibald L. Fripp	NASA Langley Research Center	Hampton	VA

	(LaRC)		
Melt Stabilization of PbSnTe in a Magnetic Field			
Dr. Archibald L. Fripp	NASA Langley Research Center (LaRC)	Hampton	VA
Gravitational Role in Liquid-Phase Sintering			
Prof. Randall M. German	Pennsylvania State University	University Park	PA
Isothermal Dendritic Growth Experiment			
Prof. Martin E. Glicksman	Rensselaer Polytechnic Institute	Troy	NY
Thermophysical Properties of Metallic Glasses and Undercooled Alloys			
Dr. William L. Johnson	California Institute of Technology	Pasadena	CA
Orbital Processing of High Quality Cadmium Telluride			
Dr. David J. Larson, Jr.	State University of New York, Stoney Brook	Stony Brook	NY
Crystal Growth of II-VI Semiconducting Alloys by Directional Solidification			
Dr. Sandor L. Lehoczky	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL
Growth of Solid Solution Single Crystals			
Dr. Sandor L. Lehoczky	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL
GaAs Crystal Growth Experiment			
Prof. David H. Matthiesen	Case Western Reserve University	Cleveland	OH
Diffusion Processes in Molten Semiconductors			
Prof. David H. Matthiesen	Case Western Reserve University	Cleveland	OH
The Study of Dopant Segregaton Behavior During the Growth of GaAs in Microgravity			

Prof. David H. Matthiesen	Case Western Reserve University	Cleveland	OH

Temperature Dependence of Diffusivities in Liquid Metals

Prof. Franz E. Rosenberger	University of Alabama, Huntsville	Huntsville	AL

Particle Engulfment and Pushing by Solidifying Interfaces

Dr. Doru M. Stefanescu	University of Alabama, Tuscaloosa	Tuscaloosa	AL

Crystal Growth of ZnSe and Related Ternary Compound Semiconductors by Physical Vapor Transport

Dr. Ching-Hua Su	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Measurement of Viscosity and Surface Tension of Undercooled Melts

Dr. Julian Szekely	Massachusetts Institute of Technology (MIT)	Cambridge	MA

Test of Magnetic Damping of Convective Flows in Microgravity

Dr. Frank R. Szofran	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Coarsening in Solid-Liquid Mixtures

Prof. Peter W. Voorhees	Northwestern University	Evanston	IL

Vapor Growth of Alloy-Type Semiconductor Crystals

Dr. Heribert Wiedemeier	Rensselaer Polytechnic Institute	Troy	NY

Ground Experiments

Analysis of Residual Acceleration Effects on Transport and Segregation

Prof. J. Iwan D. Alexander	University of Alabama, Hunstville	Huntsville	AL

Synthesis and Characterization of Single Macromolecules: Mechanistic Studies of Crystallization and Aggregation

Prof. Spiro D. Alexandratos	University of Tennessee	Knoxville	TN

A Novel Electrochemical Method for Flow Visualization

Dr. Timothy J. Anderson	University of Florida	Gainesville	FL

Foam Metallic Glasses

Prof. Robert E. Apfel	Yale University	New Haven	CT

Nucleation and Cluster Formation in Levitated Droplets

Prof. Stephen Arnold	Polytechnic University, New York	Brooklyn	NY

Studies of Nucleation and Growth of Intermetallic Compounds

Prof. Robert J. Bayuzick	Vanderbilt University	Nashville	TN

Transport Phenomena During Equiaxed Solidification of Alloys

Prof. Christoph Beckermann	University of Iowa	Iowa City	IA

Gravitational Effects on the Development of Weld-Pool and Solidification Microstructures in Metal Alloy Single Crystals

Dr. Lynn A. Boatner	Oak Ridge National Laboratory	Oak Ridge	TN

Modeling of Convection and Crystal Growth in Directional Solidification of Semiconductor and Oxide Crystals

Prof. Robert A. Brown	Massachusetts Institute of Technology (MIT)	Cambridge	MA

Microstructure Formation During Directional Solidification of Binary Alloys Without Convection: Experiment and Computation

Prof. Robert A. Brown	Massachusetts Institute of Technology (MIT)	Cambridge	MA

Evolution of Crystal and Amorphous Phase Structure During Processing of Thermoplastic Polymers

Prof. Peggy Cebe	Tufts University	Medford	MA

Optical Properties for High Temperature Materials Research

Dr. Ared Cezairliyan	National Institute of Standards and Technology (NIST)	Gaithersburg	MD

Microgravity Chemical Vapor Deposition

Dr. Ivan O. Clark	NASA Langley Research Center (LaRC)	Hampton	VA

Glass Formation and Nucleation in Microgravity: Containerless-Processed, Inviscid Silicate/Oxide Melts (Ground-Based Studies)

Dr. Reid F. Cooper	University of Wisconsin, Madison	Madison	WI

Directional Solidification in 3He-4He Alloys

Prof. Arnold Dahm	Case Western Reserve University	Cleveland	OH

Advanced Photonic Materials Produced by Containerless Processing

Dr. Delbert E. Day	University of Missouri, Rolla	Rolla	MO

The Effect of Gravity on Natural Convection and Crystal Growth

Dr. Graham D. de Vahl Davis	University of New South Wales	Sydney	AU

Use of Synchrotron White Beam X-ray Topography for the Characterization of the Microstructural Development of Crystal - Normal Gravity Versus Microgravity

Dr. Michael Dudley	State University of New York, Stony Brook	Stony Brook	NY

Reverse Micelle Based Synthesis of Microporous Materials in Microgravity

Prof. Prabir K. Dutta	Ohio State University	Columbus	OH

Investigation of Local Effects on Microstructure Evolution

Dr. Donald O. Frazier	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Electronic Materials

Mr. Thomas K. Glasgow	NASA Lewis Research Center (LeRC)	Cleveland	OH

Combustion Synthesis of Materials in Microgravity

Prof. Irvin Glassman	Princeton University	Princeton	NJ

Evolution of Microstructural Distance Distributions in Normal Gravity and Microgravity

Prof. Arun M. Gokhale	Georgia Institute of Technology	Atlanta	GA

Evaluation of Microstructural Development in Undercooled Alloys

Dr. Richard N. Grugel	University Space Research Association (USRA)	Huntsville	AL

Influence of Free Convection in Dissolution

Prof. Prabhat K. Gupta	Ohio State University	Columbus	OH

Noncontact Thermal, Physical Property Measurement of Multiphase Systems

Dr. Robert H. Hauge	Rice University	Houston	TX

Microgravity Processing of Oxide Superconductors

Dr. William Hofmeister	Vanderbilt University	Nashville	TN

Non-Equilibrium Phase Transformations

Dr. Kenneth A. Jackson	University of Arizona	Tucson	AZ

Combined Heat Transfer Analysis of Crystal Growth

Dr. Mohammad Kassemi	Ohio Aerospace Institute	Cleveland	OH

Fundamentals of Thermomigration of Liquid Zones Through Solids

Prof. Michael J. Kaufman	University of Florida	Gainesville	FL

Compositional Dependence of Phase Formation and Stability

Prof. Kenneth F. Kelton	Washington University	St. Louis	MO

Solutocapillary Convection Effects on Polymeric Membrane Morphology

Prof. William B. Krantz	University of Colorado, Boulder	Boulder	CO

Containerless Property Measurement of High-Temperature Liquids

Dr. Shankar Krishnan	Containerless Research, Inc.	Evanston	IL

Noise and Dynamical Pattern Selection in Solidification

Prof. Douglas A. Kurtze	North Dakota State University	Fargo	ND

Microstructural Development during Directional Solidification of Peritectic Alloys

Dr. Thomas A. Lograsso	Iowa State University	Ames	IA

Numerical Investigation of Thermal Creep and Thermal Stress Effects in Microgravity Physical Vapor Transport

Dr. Daniel W. Mackowski	Auburn University	Auburn University	AL

Polymerizations in Microgravity: Traveling Fronts, Dispersions, Diffusion and Copolymerizations

Prof. Lon J. Mathias	University of Southern Mississippi	Hattiesburg	MS

Quantitative Analysis of Crystal Defects by Triple Crystal X-Ray Diffraction

Dr. Richard J. Matyi	University of Wisconsin, Madison	Madison	WI

The Interactive Dynamics of Convection, Flow and Directional Solidification

Prof. T. Maxworthy	University of Southern California	Los Angeles	CA

Y2BaCuO5 Segregation in YBa2Cu3O7-x During Melt Texturing

Dr.. Paul J. McGinn	University of Notre Dame	Notre Dame	IN

Interaction of Hele-Shaw Flows with Directional Solidification: Numerical Investigation of the Nonlinear Dynamical Interplay and Control Strategies

Prof. Eckart H. Meiburg	University of Southern California	Los Angeles	CA

The Synergistic Effect of Ceramic Materials Synthesis Using Vapor-Enhanced Reactive Sintering Under Microgravity Conditions

Prof. John J. Moore	Colorado School of Mines	Golden	CO

Diffusion, Viscosity, and Crystal Growth in Microgravity

Prof. Allan S. Myerson	Polytechnic University, New York	Brooklyn	NY

An Electrochemical Method to Measure Diffusivity in Liquid Metals

Prof. Ranga Narayanan	University of Florida	Gainesville	FL

Crystal Growth and Segregation Using the Submerged Heater Method

Prof. A. G. Ostrogorsky	Rensselaer Polytechnic Institute	Troy	NY

Investigation of "Contactless" Crystal Growth by Physical Vapor Transport

Dr. Witold Palosz	Universities Space Research Association	Huntsville	AL

Containerless Processing for Controlled Solidification Microstructures

Prof. John H. Perepezko	University of Wisconsin, Madison	Madison	WI

Containerless Processing of Composite Materials

Prof. John H. Perepezko	University of Wisconsin, Madison	Madison	WI

Comparison of the Structure and Segregation in Dendritic Alloys Solidified in Terrestrial and Low Gravity Environments

Prof. David R. Poirier	University of Arizona	Tucson	AZ

Kinetics of Phase Transformation in Glass Forming Systems

Dr. Chandra S. Ray	University of Missouri, Rolla	Rolla	MO

The Effects of Microgravity on Vapor Phase Sintering

Prof. Dennis W. Readey	Colorado School of Mines	Golden	CO

Modeling of Detached Solidification

Dr. Liya L. Regel	Clarkson University	Potsdam	NY

Drop Tube Operation

Dr. Michael B. Robinson	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Measurement of the Optical and Radiative Properties of High-Temperature Liquid Materials by FTIR Spectroscopy

Dr. Michael B. Robinson	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Undercooling Behaving of Immiscible Metal Alloys in the Absence of Crucible Induced Nucleation

Dr. Michael B. Robinson	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Undercooling Limits in Molten Semiconductors and Metals: Structure and Superheating Dependencies

Dr. Frank G. Shi	University of California, Irvine	Irvine	CA

Double Diffusive Convection during Growth of Lead Bromide Crystals

Dr. N. B. Singh	Westinghouse Electric Corporation	Pittsburgh	PA

Crystal Nucleation, Hydrostatic Tension, & Diffusion in Metal and Semiconductor Melts

Prof. Frans A. Spaepen	Harvard University	Cambridge	MA

Micro- and Macro-Segregation in Alloys Solidifying with Equiaxed Morphology

Dr. Doru M. Stefanescu	University of Alabama, Tuscaloosa	Tuscaloosa	AL

The Impaction, Spreading, and Solidification of a Partially Solidified Undercooled Drop

Dr. Julian Szekely	Massachusetts Institute of Technology (MIT)	Cambridge	MA

Microporous Membrane and Foam Production by Solution Phase Separation: Effects of Microgravity and Normal Gravity Environments on Evolution of Phase Separated Structures

Dr. John M. Torkelson	Northwestern University	Evanston	IL

Fundamentals of Mold-Free Casting Experimental and Computational Studies

Prof. Gritar Tryggvason	University of Michigan	Ann Arbor	MI

Electromagnetic Field Effects in Semiconductor Crystal Growth

Dr. Martin P. Volz	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Containerless Liquid Phase Processing of Ceramic Materials

Dr. Richard Weber	Containerless Research, Inc.	Evanston	IL

BSO/BTO Identification of Gravity Related Effects on Crystal Growth, Segregation, and Defect Formation

Prof. August F. Witt	Massachusetts Institute of Technology (MIT)	Cambridge	MA

LOW-TEMPERATURE MICROGRAVITY PHYSICS

Overview

The objective of the low-temperature microgravity physics program during FY 1995 was to provide the opportunity to test fundamental scientific theories to a level of accuracy not possible in the normal gravity environment on Earth. The research was directed at achieving measurements at new levels of resolution that would serve as standards for years to come. The low-temperature microgravity physics program encompasses research on transient and equilibrium critical phenomena, effects of boundaries on matter, superfluid hydrodynamics, quantum crystal growth and dynamics, laser cooling of atoms, and relativity and gravitational physics.

In FY 1995, the program released an NASA Research Announcement in combination with the fluid physics program. With 92 proposals received, the low-temperature microgravity physics discipline almost tripled the number of responses received in 1991. Of these proposals, 65 were in the area of low temperature physics and 27 were in laser cooling of atoms. Selections for awards will be made in FY 1996.

FY 1995 saw exciting new developments for the low temperature research capabilities for the planned International Space Station with the decision to develop a Low-Temperature Microgravity Physics Facility. This facility is planned for launch in 2002 and will be designed to be an unpressurized attached payload on the Japanese Experiment Module's Exposed Facility. Research areas supported by the Low-Temperature Microgravity Physics Facility include: studies of critical phenomena, finite size effects, non-equilibrium phenomena, superfluid hydrodynamics, and quantum crystal growth and dynamics.

The sixteen ongoing ground-based tasks have now matured to the level where they are producing many exciting new results in their investigations. The sum of all of the proceedings, journal articles, and presentations totals 85 publications by these investigators during FY 1995. Most notable amongst these reports is the announcements of the following three new discoveries:

§ Professor Guenter Ahlers and his associate Dr. Feng Chuan Liu of the University of California at Santa Barbara have discovered a new state of liquid helium. They report that when the liquid is held in the superfluid part of its phase diagram but very close to the superfluid-normal fluid transition in liquid helium, and has impressed upon it a heat current, it displays a thermal resistance that is much larger than normally observed in superfluid helium, but still smaller than the thermal resistance of the normal fluid. These measurements have a direct relationship on the flight experiment Critical Dynamics in Microgravity Experiment.

§ Professors Humphrey Maris and George Seidel of Brown University are studying drops of liquid helium levitated with a superconducting magnet. Their task will investigate the flows that are created in the drops when the drops are caused to rotate. On introducing drops into the magnetic trap, they found that, if two drops enter the trap together, the two contacting drops can persist as separate entities for times of up to several minutes before coalescing. After control of the temperature was improved, they found that this non-coalescence occurred only when the drops are in the normal fluid state; when the drops cool into the superfluid state, they immediately coalesce. High speed video images of the coalescence process are being recorded to better study these new phenomena.

§ Professor Charles Elbaum of Brown University is studying the solid-liquid phase change in helium. At low temperatures, there exist two forms of the solid: the hexagonal close-packed form occupies most of the phase diagram while the face-centered cubic form exists only in a narrow region near the superfluid-normal fluid transition and very near the melting curve. Elbaum and his coworkers have observed the nucleation of the non-equilibrium body-centered cubic form under certain conditions and have identified a new phenomenon of nucleation in a first order phase transition whereby a non-equilibrium phase nucleates and persists in a metastable state. These events can be accounted for in terms of solid helium -- superfluid interfacial free energy differences for the two solids and resulting different nucleation probabilities for different values of supercooling.

Meetings, Awards, Publications

A paper summarizing the main results from the flight of the Lambda Point Experiment was published in the prestigious journal, Physical Review Letters. The Lambda Point Experiment confirmed the validity of the Nobel Prize winning Renormalization Group theory of critical phenomena with unprecedented resolution and accuracy; this theory constitutes one of the greatest achievements of theoretical physics of the past 30 years.

Professor Randall Hulet (Rice University), a recently selected principal investigator in the Low-Temperature Microgravity Physics program, received the prestigious 1995 American Physical Society I. I. Rabi Prize in Atomic Physics. This award was for his pioneering work on statistical studies of laser-cooled atoms.

Flight Experiments

The Critical Dynamics in Microgravity Experiment team led by Dr. Robert Duncan has worked to set up an experiment probe for measuring the thermal conductivity of liquid helium very near the transition where the liquid becomes 'superfluid', i.e., where liquid helium begins to display unusual properties like zero viscosity and near-infinite thermal conductivity. The experiment will help to understand these transitions by studying the heat conduction near the transition with high precision instrumentation. The experimental probe will be used by the Critical Dynamics in Microgravity Experiment team at the University of New Mexico to demonstrate the feasibility of the measurements that were proposed for a flight experiment.

In FY 1995, the Confined Helium Experiment made a transition from instrument development to performance testing with integrated instrument and flight electronics. With assistance from Northeastern University, a design was worked out for a calorimeter that incorporates a stack of 392 thin silicon wafers to confine the liquid helium. The technique has allowed new high resolution thermometers with superior performance over those used in the Lambda Point Experiment to be constructed. Simulations of these new thermometers show that the degradation of performance caused by cosmic rays on the Lambda Point Experiment flight will be largely eliminated for the Confined Helium Experiment. Recent noise measurements of the flight thermometers have confirmed the good results seen with earlier prototype devices.

Additional tests have been performed at NASA's Jet Propulsion Laboratory on the flight cryostat and the required performance has been verified. Preparations are now underway for the integration of the instrument into the flight cryostat, followed by a full schedule of environmental testing.

The FY 1995 ground and flight tasks for low-temperature microgravity physics are listed in Table 4.5.

Table 4.5 Low Temperature Microgravity Physics Tasks Funded by MSAD in FY 1995

Flight Experiments

Critical Dynamics in Microgravity			
Dr. Robert V. Duncan	Sandia National Labs, and Univ. of New Mexico	Albuquerque	NM
Satellite Test of the Equivalence Principle (STEP)			
Prof. C. F. Everitt	Stanford University	Stanford	CA
Critical Fluid Light Scattering Experiment - ZENO			
Prof. Robert W. Gammon	University of Maryland	College Park	MD
Confined Helium Experiment (CHeX)			

Prof. John A. Lipa	Stanford University	Stanford	CA

Ground Experiments

Kinetic and Thermodynamic Studies of Melting-Freezing of Helium in Microgravity

Prof. Charles Elbaum	Brown University	Providence	RI

Ultra-Precise Measurements with Trapped Atoms in a Microgravity Environment

Dr. Daniel J. Heinzen	University of Texas, Austin	Austin	TX

Dynamics of Superfluid Helium in Low Gravity

Mr. David J. Frank	Lockheed Martin Missiles & Space Co.	Palo Alto	CA

Precise Measurements of the Density and Thermal Expansion of 4He Near the Lambda Transition

Dr. Donald M. Strayer	Jet Propulsion Laboratory (JPL)	Pasadena	CA

Theoretical Studies of the Lambda Transition of Liquid 4He

Prof. Efstratios Manousakis	Florida State University	Tallahassee	FL

Superfluid Transition of 4He in the Presence of a Heat Current

Prof. Guenter Ahlers	University of California, Santa Barbara	Santa Barbara	CA

Equilibration in Density and Temperature Near the Liquid-Vapor Critical Point

Prof. Horst Meyer	Duke University	Durham	NC

Dynamics and Morphology of Superfluid Helium Drops in a Microgravity Environment

Prof. Humphrey J. Maris	Brown University	Providence	RI

Condensate Fraction in Superfluid Helium Droplets

Prof. J. Woods Halley	University of Minnesota	Minneapolis	MN

Effect of Confinement on Transport Properties by Making use of Heium Near the

Lambda Point

Prof. John A. Lipa	Stanford University	Stanford	CA

Atom Interferometry in a Microgravity Environment

Dr. Mark A. Kasevich	Stanford University	Stanford	CA

Microgravity Test of Universality and Scaling Predictions Near the Liquid-Gas Critical Point of 3He

Dr. Martin B. Barmatz	Jet Propulsion Laboratory (JPL)	Pasadena	CA

Nucleation of Quantized Vortices from Rotating Superfluid Drops

Prof. Russell J. Donnelly	University of Oregon	Eugene	OR

Measurement of the Heat Capacity of Superfluid Helium in a Persistent-Current State

Dr. Talso C. Chui	Jet Propulsion Laboratory (JPL)	Pasadena	CA

Nonequilibrium Phenomena Near the Lambda Transition of 4He

Dr. Talso C. Chui	Jet Propulsion Laboratory (JPL)	Pasadena	CA

Dynamic Measurement Near the Lambda-Point in a Low-g Simulator on the Ground

Dr. Ulf E. Israelsson	Jet Propulsion Laboratory (JPL)	Pasadena	CA

5: TECHNOLOGY, HARDWARE, AND EDUCATION OUTREACH

ADVANCED TECHNOLOGY DEVELOPMENT IN 1995

The Advanced Technology Development Program was established for NASA's Microgravity Science Research Program in response to the challenges researchers faced when defining experiment requirements and designing associated hardware. Investing in technology development is necessary if the United States intends to remain a top competitor in future scientific research. Technology researchers help ensure that the United States continues its forward strides in the fields of technology development and scientific experimentation.

Focused and broadly based technology development projects are designed to address scientific concerns in two directions. Focused research ensures the availability of required technologies which satisfy the science requirements and the flight applications of specific flight programs. Broadly based research is a long-term, proactive approach to meeting the needs of future projects and missions, which contribute to the technology base within the United States.

Microgravity Technology Development Goals

The goal of the Advanced Technology Development Program is to enable new scientific investigations by:

- Enhancing the capability of experimental hardware available to the researcher;
- Overcoming technology-based constraints to microgravity science research capabilities.

The intent of the program is to investigate and develop high-risk microgravity research technologies prior to their being needed on the critical development path for actual flight hardware. Depending on its state of maturity, the technology may either directly transition to a specific ground-based or flight program or require further development for a specific program requirement. Ideally, the successful completion of a technology task will increase confidence and reduce risk and cost in the transition to flight hardware application in microgravity programs.

Scope of Projects

Advanced Technology Development projects encompass a broad range of technology developed activities. Project funding includes the development of diagnostic instrumentation and measurement techniques, observational instrumentation and data-recording methods, acceleration characterization and control techniques, and advancements in methodologies associated with hardware design technology.

The NASA centers involved in the Advanced Technology Development program are: the Jet Propulsion Laboratory (JPL) , Goddard Space Flight Center (GSFC), Johnson Space Center (JSC) , Langley Research Center (LaRC), Lewis Research Center (LeRC) and Marshall Space Flight Center (MSFC). The projects listed below indicate the breadth of technologies covered by the program during FY 1995. A more detailed description of the projects can be found in the FY 1995 Microgravity Technology Report. Table 5.1 lists the principal investigators for the projects discussed below.

1995 Advanced Technology Development Projects

Free-Float Trajectory Management: The objective of this activity is the production of an extended, consistently reproducible acceleration setting during the stabilized low-gravity phase of the trajectory for free-float packages aboard aircraft which serve as testing units for microgravity investigations. In FY 1995 the development of the free-float test rack and aircraft-mounted control rack hardware was completed. Aircraft parameter identification studies began during the last quarter of FY 1995.

Stereo Imaging Velocimeter: Research in this area will provide a method to quantitatively measure three-dimensional fluid velocities by mapping and tracking multiple tracer particles whose locations are determined from two camera images. One use of this technology involves multipoint particle tracking during convective flow studies. A fully operational Stereo Imaging Velocimeter breadboard system was completed in FY 1995.

Real-Time X-ray Transmission Microscope for Solidification Processing: A high resolution x-ray microscope which views in situ and in real-time, the interfacial processes in metallic systems during freezing is being developed; research goals include study of solidification of metals and semiconductors and the dispersion of reinforcement particles in composites. Research and development of camera/converter technology continued in FY 1995.

Advanced Heat Pipe Technology for Furnace Element Design: Development a heat pipe which operates as an isothermal furnace liner capable of processing materials at temperatures up to 1500 C and of a furnace, with no moving parts, which can solidify or cool materials with a high degree of control are the two goals of this project. This Moving Gradient Heat Pipe Furnace will allow advances in crystal growth and other materials science investigations. In FY 1995, researchers identified the most cost-effective materials and design for fabricating the high-temperature heat pipe. The first three pipes were designed and fabrication has been initiated.

Microgravity Combustion Diagnostics: In order to improve the diagnostic techniques available to microgravity combustion scientists the following nonintrusive techniques are being investigated: two-dimensional temperature measurement, exciplex fluorescence droplet diagnostics, full-field infrared emission imaging, and velocity field diagnostics using both laser droplet velocimetry and particle image velocimetry. In FY 1995, an end-to-end calibration of the infrared sensitive staring array camera was conducted; initial low gravity testing has begun.

Small, Stable, Rugged Microgravity Accelerometer: This project is designed to produce a working accelerometer with improved performance, higher sensitivity, simplified calibration procedures and lower cost due to decreased size and mass. Experiments on smaller payloads will benefit from this miniaturized design. By the end of FY 1995, a prototype had been developed.

High-Resolution Pressure Transducer and Controller: High-resolution pressure transducers and controllers are being designed under this project to provide improved performance. These devices will be used to support both ground and flight microgravity research. Performance testing of the improved design was conducted in FY 1995.

Single Electron Transistor: This project will develop a Single Electron Transistor using niobium technology to enhance performance and allow operation at higher temperatures. One application for this technology is in read-out electronics for thermophysical measurements at low temperatures. In FY 1995, demonstration devices were fabricated.

Surface Light Scattering Instrument: This research provides a method for noninvasively measuring surface tension and viscosity and measuring temperature and surface tension gradients at a fluid surface without contact. Applications include critical point studies, free-surface phenomena experiments, and surface tension driven convection experiments. Construction of the fiber optic version of this instrument was completed and tested in FY 1995.

The Laser-Feedback Interferometer: A New, Robust, and Versatile Tool for Measurements of Fluid Physics Phenomena: This project will develop an instrument which uses a laser as both a light source and a phase detector in order to determine phenomena that are dynamic and that vary slowly over time in microscopic and macroscopic fields-of-view. This technology has applications in several scientific fields. In FY 1995 an instrument was constructed and preliminarily calibrated.

Crystal Growth Instrumentation Development: A Protein Crystal Growth Studies Cell: A user-friendly system for real-time protein crystal growth research in the microgravity environment will be developed under this project. Design analysis goals include the measurement of face growth rates, solution concentration gradients, and interfacial features of the crystals in either quiescent or direct-flow velocity solutions. The preliminary development of his system was completed and interfacing was initiated by the end of FY 1995.

High-Resolution Thermometry and Improved Readout: This project will develop a high-resolution penetration depth thermometer using a two-stage series array superconducting quantum interference device to overcome thermal fluctuation and particle radiation problems in measuring and controlling the thermodynamic state of samples. During FY 1995, Penetration Depth Thermometer (PDT) sensors were fabricated using aluminum films as the sensitive elements, testing and evaluation work continued.

Determination of Soot Volume Fraction Via Laser-Induced Incandescence: Laser-induced incandescence is being studied for use as a two-dimensional imaging diagnostic tool for the measurement of soot volume fraction. This technology offers more detailed information about combustion processes than present line-of-sight measurements. FY 1995 accomplishments include characterization of the spectral and temporal nature of the Laser-Induced Incandescence signal, as well as excitation wavelength and intensity dependencies.

Multi-Color Holography: This project tests a previously developed theory which suggests that direct simultaneous measurement of temperature and concentration variations in fluids is possible through the use of noninvasive, multi-wavelength holographic techniques. This technology offers significant reduction in the number of experiment runs necessary to validate basic science principles. Accomplishments through FY 1995 include the development of a miniature system that can fly aboard the KC 135 experimental aircraft.

Ceramic Cartridges via Sintering and Vacuum Plasma Spray: Plasma sprays are being used to form multiple layer containment cartridges for use in single crystal growth studies; this technology will have applications for manufacturing refractory crucibles and passively cooled rocket nozzles. Through FY 1995, parameter development and deposit characterization have been completed for a variety of refractory materials.

Table 5.1 Advanced Technology Development Funded by MSAD in FY 1995

Free-Float Trajectory Management ATD			
Mr. A. P. Allan	University of Delaware	Wilmington	DE
Stereo Imaging Velocimetry			
Dr. Mark Bethea	NASA Lewis Research Center (LeRC)	Cleveland	OH
Real-Time X-Ray Microscopy for Solidification Processing			
Dr. Peter A. Curreri	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL
Advanced Heat Pipe Technology for Furnace Element Design			
Dr. Donald C. Gillies	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL
Microgravity Combustion Diagnostics			
Dr. Paul S. Greenberg	NASA Lewis Research Center (LeRC)	Cleveland	OH
Small, Stable, Rugged Microgravity Accelerometer			
Dr. Frank T. Hartley	Jet Propulsion Laboratory (JPL)	Pasadena	CA
High-Resolution Pressure Transducer and Controller			
Dr. Ulf E. Israelsson	Jet Propulsion Laboratory (JPL)	Pasadena	CA
Single Electron Transistor (SET)			
Dr. Ulf E. Israelsson	Jet Propulsion Laboraytory (JPL)	Pasadena	CA
Surface Light Scattering Instrument			

Dr. William V. Meyer	Ohio Aerospace Institute	Cleveland	OH
The Laser Feedback Interferometer: A New, Robust, and Versatile Tool for Measurements of Fluid Physics Phenomena			
Dr. Ben Ovryn	Nyma, Inc.	Cleveland	OH
Crystal Growth Instrumentation Development: A Protein Crystal Growth Studies Cell			
Dr. Marc L. Pusey	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL
High-Resolution Thermometry and Improved SQUID Readout			
Dr. Peter Shirron	Goddard Space Flight Center (GSFC)	Greenbelt	MD
Determination of Soot Volume Fraction Using Laser-Induced Incandescence			
Dr. Randall L. Vander Wal	NASA Lewis Research Center (LeRC)	Cleveland	OH
Multi-Color Holography			
Mr. William K. Witherow	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL
Ceramic Cartridges Via Sintering and Vacuum Plasma Spray			
Dr. Frank R. Zimmerman	NASA Marshall Space Flight Center (MSFC)	Huntsville	AL

Technology Transfer Programs

Several on-going technology transfer activities, including laser light scattering, stereo imagining velocimetry, advanced furnace, and bioreactor technologies were pursued in FY 1995. A new technology transfer program with a goal of transferring electrostatic levitation and microwave processing technologies to industry was initiated at NASA's Jet Propulsion Laboratory in FY 1995. Seven technology cooperation agreements have been signed and five technology affiliates contracts are under negotiation.

Microgravity Technology Report

In December 1995, NASA's first Microgravity Technology Report was published. This document covers technology policies, technology development, and technology transfer activities within the microgravity research programs from 1978 through FY 1994. It also describes the recent major tasks initiated under the Advanced Technology Development Program and identifies current technology requirements. Annual editions of this document will be issued beginning with FY 1995.

Experiment Hardware For Space Shuttle And Mir Flights

A significant effort was spent in FY 1995 in preparation of multi-user and experiment-unique apparatus for Space Shuttle and Mir missions. Listed below in Table 5.2 are Shuttle missions with significant microgravity experiments and the US developed flight experimental apparatus that have been in use and are under development in the Microgravity Science Research Program to support these missions. A list of flight experimental hardware being developed by international partners which will be used by US investigators appears in Table 5.3.

Table 5.2 - Shuttle Missions With Major Microgravity Equipment On-board.

Mission	Full Name	Launch Date	Flight
SL-3	Spacelab - 3	April 1985	STS-51-B
IML-1	International Microgravity Laboratory-1	January 1992	STS-42
USML-1	United States Microgravity Laboratory-1	June 1992	STS-50
USMP-1	United States Microgravity Payload-1	October 1992	STS-52
USMP-2	United States Microgravity Payload-2	March 1994	STS-62
IML-2	International Microgravity Laboratory-2	July 1994	STS-65
Mir-1	Shuttle/Mir-1	June 1995	STS-71
**	Wake Shield Facility, Spartan	September 1995	STS-69
USML-2	United States Microgravity Laboratory-2	October 1995	STS-73
Mir-2	Shuttle/Mir-2	November 1995	STS-74
USMP-3	United States Microgravity Payload-3	February 1996	STS-75
Mir-3	Shuttle/Mir-3	April 1996	STS-76
LMS	Life and Microgravity Spacelab	June 1996	STS-78
Mir-4	Shuttle/Mir-4	August 1996	STS-79
Mir-5	Shuttle/Mir-5	December 1996	STS-81
MSL-1	Microgravity Spacelab-1	April 1997	STS-83
Mir-6	Shuttle/Mir-6	May 1997	STS-84
**	Crista-Spas-2, Japanese Experiment Module Flight Demonstration	July 1997	STS-85

Mir-7	Shuttle/Mir-7	September 1997	STS-86
USMP-4	United States Microgravity Payload-4	October 1997	STS-87

**** Middeck and Get-Away-Special MicrogravityPayloads Only.**

Advanced Automated Directional Solidification Furnace: This instrument is a modified Bridgman-Stockbarger furnace for directional solidification and crystal growth (USMP -3,-4).

Combustion Module-1: This module is being developed for performance of multiple combustion experiments in space; the first two experiments will be the Laminar Soot Processes experiment and the Structure of Flame Balls at Low Lewis Number experiment. (MSL-1).

Critical Fluid Light Scattering Experiment: This apparatus provides a micro-Kelvin controlled thermal environment and dynamic light scattering and turbidity measurements for critical fluid experiments (USMP- 2, - 3).

Critical Viscosity of Xenon: This apparatus provides a precision controlled thermal environment (micro-Kelvin) and an oscillating screen viscometer to enable viscosity measurements for critical fluids (STS-85).

Crystal Growth Furnace: This instrument is a modified Bridgman-Stockbarger furnace for crystal growth from a melt or vapor (USML- 1, -2).

Biotechnology System: This instrument is composed of a rotating wall vessel Rbioreactor,S a control computer, a fluid supply system, and a refrigerator for sample storage (Mir).

Drop Physics Module: This apparatus is designed to investigate the surface properties of various suspended liquid drops, to study surface and internal features of drops that are being vibrated and rotated, and to test a new technique for measuring surface tension between two immiscible fluids (USML- 1, -2).

Droplet Combustion Experiment: The apparatus is designed to study droplet behavior during combustion by measuring burning rates, extinction phenomena, disruptive burning, and soot production (MSL-1).

Geophysical Fluid Flow Cell: This instrument uses electrostatic forces to simulate gravity in a radially symmetric vector field, centrally directed toward the center of the cell. This allows investigators to perform visualizations of thermal convection and other research related topics in planetary atmospheres and stars (SL-3, USML-1, 2).

Isothermal Dendritic Growth Experiment: The apparatus is being used to study the growth of dendritic crystals in transparent materials that simulate some aspects of pure metals and metal alloy systems (USMP- 2, -3, -4).

Low-Temperature Microgravity Physics Cyrogenic Dewar: This apparatus will support different experiments on different flights. On USMP-1, it was designed to support the Lambda Point Experiment, testing the theory of confined systems using helium held near the lambda point and confined to 50 micron gaps. On USMP-4, it will support the Confined Helium Experiment. On MSP-1, it will support the Critical Dynamics in Microgravity Experiment.

Mechanics of Granular Materials: This instrument uses microgravity to gain a quantitative understanding of the mechanical behavior of cohesionless granular materials under very low confining pressures (Shuttle/Mir-4, -6).

Microgravity Smoldering Combustion: This apparatus is used to determine the smoldering characteristics of combustible materials in microgravity environments (STS-69).

Middeck Glovebox: A multi-disciplinary facility used for small scientific and technological investigations (USMP -3,-4,-5).

Mir Glovebox: A modified middeck Glovebox for collection of scientific and technological data prior to major investments in the development of more sophisticated scientific instruments (Mir).

Physics of Hard Spheres Experiment: This hardware will support an investigation to study the processes associated with liquid-to-solid and crystalline-to-glassy phase transitions (MSL-1).

Pool Boiling Experiment: This apparatus is capable of autonomous operation for the initiation, observation, and recording of nucleate pool boiling phenomena (multiple missions).

Protein Crystal Growth: Uses a variety of apparatus to evaluate the effects of gravity on the growth of protein crystals such as the Single Locker Thermal Enclosure System and the Thermal Enclosure System (multiple missions).

Solid Surface Combustion Experiment: This instrument is designed to determine the mechanism of gas-phase flame spread over solid fuel surfaces in the absence of buoyancy-induced or externally imposed gas-phase flow (multiple missions).

Space Acceleration Measurement System: The instrument is designed to measure and record the acceleration environment in the Space Shuttle Middeck and cargo bay, in the Spacelab, and in Mir (multiple missions).

Surface Tension Driven Convection Experiment: The apparatus is designed to provide fundamental knowledge of thermocapillary flows, fluid motion generated by the surface attractive force induced by variations in surface tension caused by temperature gradients along a free surface (USML-1, -2).

Orbital Acceleration Research Experiment: This instrument is developed to measure very low frequency accelerations on obit such as atmospheric drag and gravity gradient effects (multiple missions).

Transitional/Turbulent Gas Jet Diffusion Flames: This instrument will be used to study the role of large-scale flame structures in microgravity transitional gas jet flames (Get Away Special Experiment).

Table 5.3 Flight Experiment Hardware Used by NASA's Microgravity Research Program Developed by International Partners

Advanced Gradient Heating Furnace	European Space Agency
Advanced Protein Crystallization Facility	European Space Agency
Bubble, Drop and Particle Unit	European Space Agency
Biolabor	German Space Agency
Critical Point Facility	European Space Agency
Cryostat	German Space Agency
Electromagnetic Containerless Processing Facility (TEMPUS)	German Space Agency
Electrophoresis (RAMSES, Recherch? Appliqu? Sur Les Methods De Separation en Electrophorese Spatiale)	French Space Agency
Free Flow Electrophoresis Unit	National Space Agency of Japan
Glovebox	European Space Agency
Large Isothermal Furnace	National Space Agency of Japan
Materials for the Study of Interesting Phenomena of Solidification	French Space

on Earth and in Orbit (MEPHISTO, Material pour lUEtude des Phenomenes Interessant la Solidification sur Terre et en Orbit)	Agency
Microgravity Isolation Mount	Canadian Space Agency
Mirror Furnace	National Space Agency of Japan
Microgravity Measurement Assembly	European Space Agency
Quasi-Steady Acceleration Measurement	German Space Agency

Space Station Facilities For Microgravity Research

The Microgravity Science and Applications Research Program continues to develop several multi-user facilities specifically designed for long duration scientific research missions aboard the International Space Station. To obtain an optimal balance between science capabilities, costs, and risks, facility requirements definition have been aligned with evolving Space Station capabilities. In total, the Microgravity Science and Applications Research Program has now defined requirements for five multi-user facilities for the International Space Station:

§ Biotechnology Facility
§ Space Station Furnace Facility
§ Fluids and Combustion Facility
§ Microgravity Science Glovebox
§ Low Temperature Microgravity Physics Research Facility

The Biotechnology Facility is an integrated version of the original Protein Crystal Growth and Biotechnology facilities. The biotechnology application of the facility will accommodate bioreactor systems to address cell growth, and systems to support protein crystal growth using the quiescent low-gravity environment of Space Station. The facility simulators were delivered early in FY 1995 to investigators for test and check out. An independent assessment of the facility was held in March 1995. In FY 1996, the Biotechnology Facility experiment control computer will be placed on Mir to control cell and tissue culture experiments; these Mir flights will reduce the risk in the design and development of full facility operations for Space Station.

The Space Station Furnace Facility, scheduled for operation in 2000, is a facility designed to accommodate investigations in basic materials research, applications, and studies of phenomena involved in the solidification of metals and crystal growth of semiconductor materials. The facility is comprised of furnace modules and a core of integrated support subsystems. Its development has paralleled the Space Station design activity to ensure that payload requirements are incorporated in the Space Station design process. An international workshop to identify potential cooperative furnace developments was held with the Space Station international partners in Nordwijk, Holland, in June 1994, and agreements with the European Space Agency and the French Space Agency for development of additional furnace modules are being explored. A second international workshop to further refine cooperative furnace developments was held in February 1995 in Huntsville, Alabama. Modifications to the design of the US Spacelab furnace to allow it to be the first US furnace module in the facility began in late 1995.

The Fluids and Combustion Facility is designed to accommodate a wide range of microgravity fluids and microgravity combustion experiments. The precursor to the first facility combustion module, being prepared for flight on MSL-1 (FY 1997) has entered the design and development phase. The conceptual design for the fluids module and the systems made for the facility was held in December 1994. An international workshop to identify possible cooperative experiment module development in fluid physics and combustion science was held in April 1995. After successful completion of a Requirements Definition Review in 1996, the facility will proceed to the design and development phase.

The Microgravity Science Glovebox is a multi-disciplinary facility for small, low-cost, rapid-response scientific and technological investigations in the areas of material science, biotechnology, combustion science, and fluid physics, allowing preliminary data to be collected and analyzed prior to any major investment in sophisticated scientific and technological instrumentation. Negotiations with the European Space Agency are currently underway for the provision of the Glovebox by the European Space Agency in exchange for early access to Space Station capabilities. The Glovebox passed system design review at European Space Agency and by late 1995 was in the requirements review stage. Project Development Review is scheduled for April 1996.

The Low-Temperature Microgravity Physics Facility has recently been added to the Space Station payload complement. The facility will be mounted externally to the station at one of the attach points of the Japanese Experiment Module's Exposed Facility. The United States and Japan have negotiated agreements which permit the United States to use from three to five of the Exposed Facility's 10 attach points, as well as racks within the Japanese Experiment Module. Definition activities for the Low-Temperature Microgravity Physics Facility were initiated in the fall of 1995.

In addition to the science facilities on the station, Telescience Support Centers are being developed at the Lewis Research Center and Marshall Space Flight Center to support microgravity operations on the International Space Station. These facilities are co-located with the hardware developers and discipline scientists to support investigators. The goal is to allow investigators to operate as much as possible from their home institutions. In FY 1994, the Lewis Research Center's facility began support of on-going Shuttle missions.

Ground-Based Microgravity Research Support Facilities

NASA maintained reduced-gravity research ground facilities, including two drop towers, a drop tube, parabolic flight aircraft, and other support facilities at the Lewis Research Center and the Marshall Space Flight Center, in support of the Microgravity Research Program. Aircraft used for parabolic flight trajectories include a KC-135 aircraft at the Johnson Space Center, a Learjet Model 25 and a newly acquired DC-9 (replacing the smaller Learjet) at the Lewis Research Center, which began operations in July 1995. Table 5.4 summarizes the facilities usage in FY 1995.

Table 5.4 Use of Ground-Based Low-Gravity Facilities - FY 1995

	Zero-G	2.2- Tower	Drop Tube	KC-135	Learjet**	DC-9 *
No. of Investigations Supported	9	46	7	17	6	18
No. of Drops or Trajectories	168	1178	400	4132	164	1065
No. of Flights (Flight Hours)	n/a	n/a	n/a	36 (192.3)	33 (52.8)	45 (92.4)

* Began operations July 1995.
** Ceased operations June 1995.

Education and Outreach Activities

The highlight of the year for the microgravity sciences education program was the February 2, 1995, RPutting the `gee!' in Microgravity" national live television broadcast. During the show, audiences nationwide participated in a series of research activities designed to demonstrate how seemingly well-understood biological, chemical, and physical phenomena change in the absence of the Earth's gravity. Features included interactive communication via telephone and NASA Spacelink, an electronic database of space-related information, and several NASA scientists and educators at three uplink sites: Lewis Research Center (NASA's Center for Combustion Science and Fluid Physics) in Cleveland, Ohio; the Satellite Telecommunications Educational Program/Star facility in Spokane, Washington; and Oklahoma State University in Stillwater, Oklahoma. The one-hour live broadcast presented a range of experiments that can be conducted in any classroom including ground-based investigations requiring low-gravity conditions producible in a RminiS drop tower, explaining the experiments, giving demonstrations, and fielding audience questions about the results. This telecast sparked a sharp increase in requests for microgravity science learning materials. The program was developed by NASA's Education Division as one of four programs in its "Explorations in Science, Mathematics & Technology" series for pre-college audiences and was produced for NASA's Teaching From Space Program at Langley Research Center.

Thousands of elementary and secondary school teachers attending the 1995 annual meetings of the National Science Teachers Association and the National Council of

Teachers of Mathematics had the opportunity to learn new ways to improve student understanding of the effects of normal and low gravity and the implications of microgravity research. The microgravity exhibit booth featured a small drop tower with an internal video camera to demonstrate free-fall experiments, using a slow-motion video playback to help reveal the effect of reduced gravity on physical and chemical phenomena that are normally masked by the Earth's gravity. In addition to the demonstrations, more than 4,000 microgravity teacher's guides, which include detailed suggestions for classroom activities, and 2,000 instructional posters, were distributed during the two conventions.

On May 4, 1995, NASA and the Public Broadcasting System again broadcast a live videoconference on Space Station research, focusing on the fields of life sciences, biotechnology, and technology development. The title of the video conference was RSpace Station: It's About Life on Earth,S with emphasis on how space research improves the quality of life on earth, how the microgravity environment can accelerate the rate of discovery, and how industry and universities with a stake in biotechnology can become involved. At the conclusion of the video conference, viewers were provided information on RHow To Get On Board Space StationS via Announcements of Opportunity, NASA Research Announcements for Science and Medical Research, and Announcements of Opportunities for Engineering Research and Commercial Technology. This particular video conference reflected NASA's cooperative research with industry, academia, medical institutions, and other federal agencies.

Six graduate students were selected from a national pool of 30 applicants to the Graduate Student Researchers Program to receive support for ground-based microgravity science research, with selections being based on a competitive evaluation of academic qualifications, proposed research plans, and the students' projected use of NASA research facilities. This brought to 53 the number of Graduate Student Researchers Program researchers working on microgravity research projects in FY 1995. When added to the graduate students working with NASA-funded principal investigators, this brings the number of graduate students directly employed in microgravity research to 587.

Microgravity News, a quarterly newsletter providing updates on microgravity research programs and activities, has been reaching increasing numbers of people in the past year. The December 1995 mailing list included almost 2500 subscribers, up from 934 in January 1995. Over 750 K-12 teachers asked to be added to the Microgravity News mailing list at the 1995 annual meetings of the National Science Teachers Association and the National Council of Teachers of Mathematics. A further 2000 copies of the newsletter are distributed by NASA field centers and headquarters. The increased popularity of the Newsletter is credited to the strong support staff at Hampton University which has been particularly innovative in targeting special groups. The Microgravity News is available on the internet.

The Microgravity Science Research Program's World Wide Web Home Page provides regular updates on upcoming conferences and microgravity related NASA Research Announcements. Improved links to Lewis Research Center, Marshall Space Flight

Center, Langley Research Center and Jet Propulsion Laboratory enable users to find out quickly about microgravity research being supported at the field centers. The Microgravity Homepage is on the internet.

A list of important microgravity World Wide Web Internet addresses is presented as Table 5.5.

Table 5.5 Important Microgravity World Wide Web Sites

Name	Internet Address	Description
NASA Homepage	http://www.nasa.gov	Information and links to all NASA sites.
Microgravity Sciences and Applications Division	http://microgravity. msad.hq.nasa.gov/	Microgravity Division site with links to other microgravity sites and news about programs and NRAs.
Microgravity News	http://magpie.larc.nasa. gov/news/ugnews.html	Text and graphics of Microgravity News online.
Lewis Research Center	http://www.lerc.nasa. gov/	Information on fluids and combustion research.
Marshall Space Flight Center	http://www.msfc.nasa. gov/	Information on materials science and biotechnology research.
Jet Propulsion Laboratory	http://www.jpl.nasa.gov/lowtemp	Information on low-temperature microgravity physics.
Shuttle Flights	http://www.osf.hq.nasa .gov/shuttle/Welcome.html	Information on all Shuttle flights.
Marshall	http://samson2.msfc.nasa.gov/fame/Fame.html	Information on

Space Flight Center Microgravity Experiments Database		materials science and other experiments as well as photos.
ESA Microgravity Database (MGDB)	http://www.esrin.esa.it/htdocs/mgdb/mgdbhome.html	Experiment descriptions and results, diagrams, video sequences.
Lewis Research Center Microgravity Database	http://www.lerc.nasa.gov/Other_Groups/MCFEP	Information on fluids and combustion experiments.
Langley Research Center	http://www.larc.gov/LISAR	Digital image database on-line.

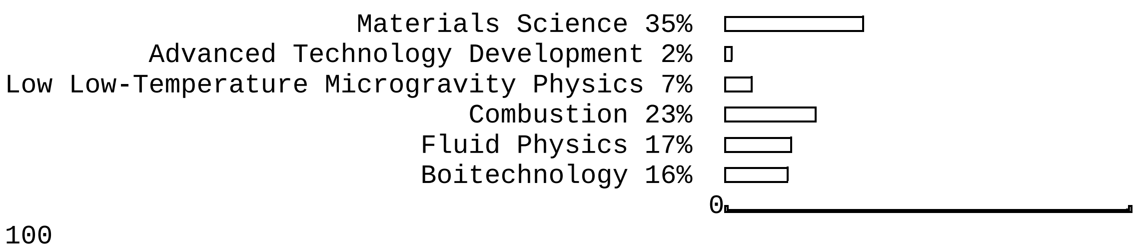
Microgravity Data Archiving

NASA continued developing the Microgravity Data Archive System in FY 1995. NASA's Marshall Space Flight Center's Microgravity Research Division began to combine its Microgravity Experiment database with the European Space Agency's database. NASA also moved more actively to make the microgravity archives in materials science and biotechnology widely accessible to the public through the World Wide Web site at the Marshall Space Flight Center. There are currently approximately 600 experiments catalogued in the Microgravity Experiment database. The Marshall Space Flight Center photo archive now has 4016 photos and the video archive has 346 VHS tapes and 16mm films cataloged.

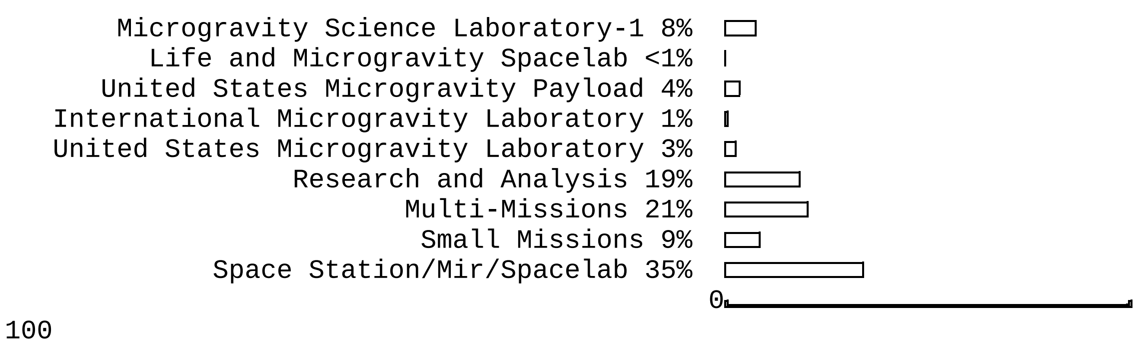
The Lewis Research Center has also been actively building its archive collection in the areas of combustion science and fluid physics. Currently, there are over 525 combustion science papers and over 246 fluid physics papers in the archive; a listing of the papers by author is currently available on the World Wide Web. Beginning in FY 1996, abstracts of the papers will be added to the Lewis Research Center World Wide Web site. The experiments database currently consists of information from a number of recent experiments. This information, contained in an Experiment Data Management Plan database, includes such items as an experiment description, a list of publications associated with the experiment, a summary of experiment results and data, and a listing of videos, photos, and digital data. In FY 1996, archivists will begin to gather data on fluids and combustion experiments from missions prior to USML-1.

6: PROGRAM RESOURCES FOR FY 1995

Funding for the FY 1995 Microgravity Science Research Program totaled $163.5 million. This budget supported an array of activities including an extensive microgravity research program, development of several microgravity Shuttle missions, Space Station planning, technology and hardware development, educational outreach, and International Space Station facility-class hardware development. The funding distribution for combined flight and ground efforts in the various microgravity research disciplines is as follows:

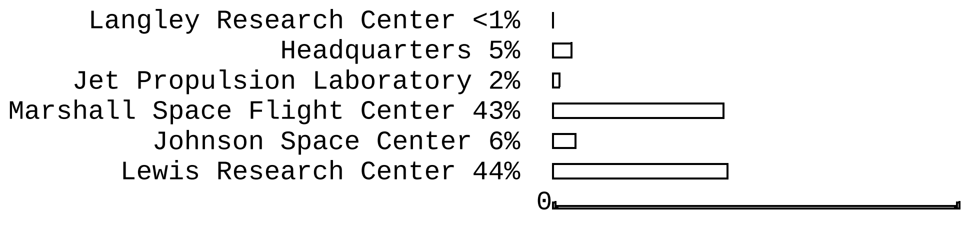


The funding distribution by microgravity mission is as follows:



Included in the above is the Research and Analysis element which supports the ground-based microgravity principal investigators not covered in a mission specific budget. The Multi-Mission category includes costs not identified with a specific mission, such as administration, the advanced technology development program, the Space Acceleration Measurement System program, data management and archiving, NIH cooperative activity, and infrastructure. The Small Missions element is the portion of the microgravity research program using the Space Shuttle Small Payload Systems (e.g., Get Away Special Canister Program), Shuttle Middeck experiments, and sounding rockets. The Space Station/Mir/Spacelab element represents funding for experiments that are planned for the Space Station and Mir programs, but could be conducted on a Spacelab if the Space Station were not available. Included in this category are the Fluids and Combustion Facility, Biotechnology Facility, and the Space Station Furnace Facility.

The Microgravity Science Research Program operates through five NASA Field Centers; the following illustrates the funding distribution among these Centers:



The microgravity program at Lewis Research Center is focused on Combustion Science and Fluid Physics, the program at the Marshall Space Flight Center is focused on Materials Science and the protein crystal growth portion of the Biotechnology discipline, the program at the Johnson Space Flight Center is focused on the cell tissue culture portion of the Biotechnology discipline, and the Jet Propulsion Laboratory program is focused on low-temperature microgravity physics. Technology development tasks were also funded in FY 1995 at each of the Field Centers.

7: PROGRAM STATUS

This section addresses activity through the second quarter of FY 1996 which impact the Microgravity Science Research Program. These activities and issues are presented here to provide the reader with a more current perspective on the evolving nature of the Program due to a rapidly changing environment.

The NASA-Mir program is continues at a swift pace and discussions are underway for addition of two more flights to the previously scheduled 7 link-up flights between the Shuttle and Mir station. Expectations are high for the other scheduled FY 1996 and 1997 flights [USML-2, USMP-3, LMS, and MSL-1] briefly described below.

Microgravity Science Flight Opportunities

Second United States Microgravity Laboratory

The Second United States Microgravity Laboratory (USML-2), built largely on the results of USML-1, was launched on October 24, 1995; preliminary results of the mission are quite promising.

In the fluid physics area, the Surface Tension Driven Convection Experiment provided researchers with a perfect opportunity to examine flows caused by surface tension differences. In addition, experiments on silicone drops with air bubbles inside conducted in the Drop Physics Module confirmed the expectation that the bubble would move to the center of the drop. Other tests in the Drop Physics Module involved the coalescence of drop with surfactants (substances that alter surface tension).

In the materials science area, USML-2 provided the conditions for growing the thinnest and smoothest mercury cadmium telluride films ever grown. Several crystal growth experiments were performed that should help improve the production of crystals on Earth. USML-2 was also the first mission to have the Microgravity Acceleration Work Station, helping scientists to guide the shuttle crew in making small orientation changes to improve crystal growth conditions.

In the biotechnology area, 1,500 protein crystals were grown on USML-2, far surpassing the number grown on any previous shuttle mission; the larger and better-ordered protein crystals grown in microgravity give researchers more clues for solving the protein's molecular structures, a first step in drug design and disease treatment.

USML-2 Glovebox experiments also yielded important results. The Particle Dispersion Experiment examined the dispersion and aggregation of fine particles in the atmosphere; information gathered could eventually reveal how nature cleanses volcanic ash or dust clouds and may lead to new strategies for coping with natural disasters. The Colloidal Disorder-Order Transition Experiment provided unique insights into one of the most fundamental questions in condensed matter physics, the transition between solid and liquid phases. Video data from the Finer-Supported Droplet Combustion Experiment also provided unprecedented observations of spherical droplets burning for up to 30 seconds and yielded new insights into soot production and detailed kinetics associated with fuel droplet combustion, with potential application to increased efficiency and reduced pollutant production in the combustion of liquid fuels.

Finally, USML-2 broke new ground in the level and sophistication of television downlink for science, with six simultaneous video channels. This allowed ground-based scientists to monitor experiments on the Shuttle to an unprecedented degree. Researchers could draw preliminary conclusions as to experiment results relative to hypotheses and make near real-time adjustments to experiment protocols.

Third United States Microgravity Payload

The Third United States Microgravity Payload (USMP-3) is scheduled for launch on February 22, 1996. Included in the compliment of facilities will be two solidification furnaces, each of which is designed to explore a different area of crystal growth. Also aboard USMP-3 will be Zeno, a facility used for examining phase change processes through the use of critical fluid light scattering phenomena. The middeck Glovebox Facility will also be included in the USMP experiment complement for the first time to accommodate smaller microgravity experiments.

With the exception of the Glovebox, which is placed in the middeck of the shuttle, USMP-3's experiment hardware will be carried on an across-the-bay structure designed for the shuttle's cargo bay and consisting of several trusses that support and protect the equipment. Of major importance, the Shuttle crew will not have direct access to the equipment as the structure is not enclosed in a pressured volume. Experiments will be directed from the Payload Operations Control Center at the Marshall Space Flight Center and the Telescience Support Center at the Lewis Research Center, which will send commands and receive data during the mission. MEPHISTO facility investigators will be monitoring the mission from France.

USMP-3 will represent new advances in telescience with investigators having real-time interaction with their experiments directly from their home institution for the first time.

Life and Microgravity Spacelab

The Life and Microgravity Spacelab (LMS) mission is a 16-day mission scheduled for launch aboard the orbiter Columbia on Shuttle flight STS-78. The flight will involve 21 investigations, six in microgravity sciences.

LMS will be the first flight of the European Space Agency's Advanced Gradient Heating Furnace, a new furnace facility available to NASA to conduct materials science investigations on the physics of multiphase solidification selected in 1992. Several European investigations will also be conducted. The Bubble, Drop and Particle Unit will be modified and used to conduct two new types of experiments for US investigators on this mission.

The microgravity science investigations will focus on protein crystallization, fluid physics and materials science. Specifically, microgravity experiments will include protein crystal growth, electrohydrodynamics, fluids interface studies, high temperature directional solidification of multi-phase materials, and solidification with particle pushing and engulfment. In addition, vibration measurement instrumentation will support these experiments by characterizing in detail the microgravity environment aboard the Spacelab.

NASA-Mir

Mir missions will focus on expanding the current Shuttle-based research program and providing an opportunity to reduce the technical risk associated with construction and operation of experiments to be conducted on the International Space Station. Microgravity research during the Mir-1 mission focused on the characterization of the acceleration environment of the Mir complex which will be used to support researchers with a profile of the acceleration levels present during the performance of their experiments. This characterization will contribute to microgravity experiment strategic planning for later Mir activities and vibroacoustics control planning activities in preparation for the Space Station. The Microgravity Glovebox will provide an opportunity to conduct fluid physics and combustion science investigations on the Mir. The Mir missions also provide a unique opportunity to advance biotechnology research with multiple and long-duration protein growth experiments which could not be supported in the short time periods of the Shuttle missions. Such biotechnology experiments with potential technological impact on medical, pharmaceutical, and agricultural industries could contribute to such areas as rational drug design and testing, disease control and treatment, and improvement and protection of commercially important crops.

Microgravity Spacelab

The 16-day Microgravity Spacelab mission (MSL-1) is scheduled for flight aboard the Space Shuttle Columbia on the STS-83 mission in the spring of 1997. More than 25 investigations in microgravity sciences, such as fluid physics, combustion science and materials science will be conducted.

Changing Workplace

NASA was caught in the Federal government furloughs of FY 1996 with the agency being shut down for 4 workdays in November, 1995 and then for an additional 21 days between December 18, 1995 and January 5, 1996 due to the lack of budget authority. A record-setting blizzard in the Washington, DC area kept NASA Headquarters closed for an additional 4 days. Other NASA Centers also were closed intermittently in January and February 1996 due to severe weather. Thus, parts of NASA lost almost a month of work time in FY 1996. The budget situation is still of concern in that NASA has taken a significant budget cut in FY 1996 and further cuts are expected for the next fiscal year. Budgets may decline by as much as 25% in purchasing power in the next five years as compared with FY 1995 funding levels. NASA's Microgravity Science Research Program can expect to share in the pain of these cuts.

The Zero-Base Review results were announced in December, 1995; this review represents the amalgamation of several reviews conducted in FY 1995 and early FY 1996 including the Shuttle Functional Workforce Review, the Independent Shuttle Workforce Review, the Federal Laboratory Review, and the NASA Headquarters Workforce Review. As a result of the Zero Base Review, the Office of Life and Microgravity Sciences has begun to move toward its RGo-ToS organization for FY 2000. Conceptually, Headquarters and Field Center activities will be functionally divided, with headquarters maintaining responsibility for addressing the Rwhat, why and for whomS issues, while the field centers will have responsibility for the Rhow.S Under current plans, the Office of Life and Microgravity Sciences personnel levels will be reduced 40 percent by FY 2000. Program science functions will remain at Headquarters but program management functions will be moved to the Field Centers.

The Zero-Base Review also addressed moving much of NASA's science to private institutes. The preliminary Science Institutes Plan outlines a conceptual framework for chartering a limited number of institutes. The plan describes the science institutes as private entities which would be established to: conduct an ongoing research program, develop and arrange for the transfer of technology, deliver services to the science community and to the public, and provide the scientific and industrial communities with access to NASA's space- and ground-based facilities. Eight of the proposed eleven institute plans require modification or further study while plans for the following three institutes have evolved to the point of near-term implementation planning: the

Biomedical Research Institute at NASA Johnson Space Center (Houston, TX), an Astrobiology Institute at NASA Ames Research Center (Moffett Field, CA), and an Institute for Microgravity Science at NASA Lewis Research Center (Cleveland, OH).

NASA Research Announcement Schedule

The Microgravity Science Research Program will be releasing additional NASA Research Announcements in 1996. The Biotechnology program expects to release a NASA Research Announcement in the second quarter of FY 1996 and Fluid Physics, Materials Science, and Low-Temperature Microgravity Physics Programs NASA Research Announcements will be released toward the end of 1996. Further NASA Research Announcements will be released for Combustion Science and Biotechnology in 1997.

Future Directions

NASA anticipates continued vibrancy of the microgravity science programs for the next several years. These programs will continue to expand the number of principal investigators as NASA approaches the space station era. Facilities development continues apace in close cooperation with our international partners. Planned shuttle missions in FY 1997 (Microgravity Science Lab - MSL-1) and FY 1998 (USMP-4) will continue to build on the world-class microgravity research already done on previous shuttle missions and will pave the final steps toward microgravity research in the space station era. NASA will continue to actively promote the application of microgravity research to diverse problems on earth such as HIV, fire safety, and industrial processes.

The future for the microgravity research program holds many challenges, but the future is very bright. The Microgravity Science Research Program looks forward to continuing to be a significant contributor to the nation's research and development program.